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Chapter 6

SUITABILITY OF THE YUCCA MOUNTAIN SITE FOR SITE CHARACTERIZATION
AND FOR DEVELOPMENT AS A REPOSITORY

The Nuclear Waste Policy Act (the Act) of 1982 (NWA, 1983) requires the
environmental assessment to include a detailed statement of the basis for
nominating a site as suitable for characterization. This detailed statement
is to be an evaluation of site suitability under the U.S. Department of
Energy (DOE) siting guidelines; the evaluation will be the basis for the
comparisons of sites reported in Chapter 7. Such an evaluation for the Yucca
Mountain site is presented in sections 6.2, 6.3, and 6.4 of this chapter. A
brief explanation of the siting guidelines--their format, structure, and
implementation--is given in Section 6.1.

6.1 THE DOE SITING GUIDELINES

As directed by Section 112 of the Act, the DOE has developed general
guidelines for siting geologic repositories. These guidelines have been
published as 10 CFR Part 960 (1984). They are to be used in the remaining
steps of the site-selection process for the first repository: the nomination
of at least five sites as suitable for characterization, the recommendation
of three sites for characterization, and the recommendation of one site for
development as a repository.

6.1.1 FORMAT AND STRUCTURE OF THE GUIDELINES

The siting guidelines are divided into implementation guidelines, post-
closure guidelines, and preclosure guidelines. The implementation guidelines
are not directly used in the evaluation of sites; their purpose is to specify
how the postclosure and preclosure guidelines are to be applied in site
screening and selection. The postclosure guidelines govern the siting
considerations that deal with the long-term behavior of a repository--that
is, its behavior after waste emplacement and repository closure. These are
the considerations most important for ensuring the long-term protection of
the health and safety of the public. The preclosure guidelines govern the
siting considerations that deal with the operation of the repository before
it is closed. These are the considerations important in protecting the
public and the repository workers from exposures to radiation during
repository operations. They are also the most important considerations in
protecting the quality of the environment and in mitigating socioeconomic
impacts because most of the environmental and socioeconomic effects of a
repository will occur during its construction and operation.

As explained in the supplementary information preceding the guidelines,
both the postclosure and the preclosure guidelines are subdivided into system
and technical guidelines. The postclosure system guideline defines general
requirements for the performance of the repository system after closure.

These requirements are based generally on the objectives of protecting public health and safety; they are based specifically on the standards proposed by the U.S. Environmental Protection Agency and released as 40 CFR Part 191 (1985) and the criteria promulgated by the Nuclear Regulatory Commission in 10 CFR Part 60 (1983). The postclosure technical guidelines specify requirements for one or more elements of the repository system—the physical properties and physical phenomena at the site.

The three preclosure system guidelines state broad requirements for three different systems. These systems include, in addition to some characteristics of the site and some engineered components, the people and the environment near the site. The elements of these systems are defined in Section III.B.4 of the supplementary information preceding the guidelines. Each of the preclosure technical guidelines specifies requirements on one or more of these elements.

Both the postclosure and the preclosure technical guidelines specify conditions that would qualify and disqualify sites, and they specify conditions that would be considered favorable or potentially adverse.

A qualifying condition is contained in each technical guideline. Taken together, these qualifying conditions are the minimum conditions for site qualification. A site will be qualified only if it meets all of the qualification conditions. A site will be disqualified if site characterization shows that it fails to meet any one of the qualifying conditions. Failure to meet a qualifying condition can usually be determined only after site characterization and the concurrent investigations of environmental and socioeconomic conditions: qualifying conditions are generally stated in terms of specifications that require analyses of the repository system, and data for such analyses will be available only at the completion of site characterization and investigation. Before site characterization, however, evaluations that compare sites will reveal the relative potential of those sites to meet the qualifying conditions.

Disqualifying conditions are contained in 12 technical guidelines. Each describes a condition that is considered so adverse as to constitute sufficient evidence to conclude, without further consideration, that a site is disqualified. Many of the 17 disqualifying conditions pertain to conditions whose presence or absence may be verifiable at a site without extensive data gathering or complex analysis.

The favorable and potentially adverse conditions can be used to predict the suitability of a site before detailed studies have been performed. They provide preliminary indications of system performance. Although favorable conditions need not exist at a given site for that site to meet the qualifying condition, the existence of such conditions leads to an expectation that subsequent evaluations will yield enhanced confidence in a site's suitability. Similarly, the purpose of determining whether any potentially adverse conditions exist at a site is to provide an early indication of conditions that must be examined carefully before judging the acceptability of that site. Such examinations must evaluate the effects of other, possibly compensatory, conditions present at a site. Thus, a site that has most of the favorable conditions may be presumed likely to meet the system guidelines,

while a site with many potentially adverse conditions can be considered to have a much greater degree of uncertainty in meeting the system guidelines.

6.1.2 USE OF THE SITING GUIDELINES IN EVALUATING SITE SUITABILITY

The evaluations of site suitability provide the basis for making the findings that Appendix III of the guidelines requires for disqualifying and qualifying conditions. Using the term apply to mean to evaluate a condition and make a finding of compliance, this appendix specifies how the guidelines are to be applied at the principal decision points of the siting process: (1) site identification as potentially acceptable, (2) nomination as suitable for characterization or recommendation for characterization, and (3) recommendation for development as a repository. In particular, this appendix specifies the types of findings that are to result from the applications of the disqualifying conditions and the qualifying conditions. Two levels of findings, one showing an increased level of confidence over the other, are specified for both the disqualifying and the qualifying conditions.

For the disqualifying conditions, a level 1 finding means that the evidence does not (or, conversely, does) support a finding that the site is disqualified. A level 2 finding, which is a higher-level finding requiring greater confidence and more extensive data to support it, means that the evidence supports a finding that the site is not disqualified on the basis of existing evidence and is not likely to be disqualified (or that the site is disqualified or is likely to be disqualified).

For the qualifying conditions, a level 3 finding is stated to mean that the evidence does not (or, conversely, does) support a finding that the site is not likely to meet the qualifying condition, while a level 4 finding, which is the higher-level finding, means that the evidence supports a finding that the site meets the qualifying condition and is likely to continue to meet the qualifying condition (or that the site cannot meet the qualifying condition and is unlikely to be able to meet it).

For a site to be nominated, at least a level 1 finding must be made for each disqualifying condition, and at least a level 3 finding must be made for each qualifying condition. For a site to be recommended for development as a repository, a level 2 finding must be made and supported for each disqualifying condition, and a level 4 finding must be made and supported for each qualifying condition.

In conducting the suitability evaluations for the site, the higher-level finding was made wherever the evidence supported it. Most often, however, the available data were inadequate for supporting the higher-level findings, which must wait for the results of site characterization and investigations as well as for the final design of the repository.

An identification of the favorable conditions and potentially adverse conditions present at the site is necessary for evaluating the ability of the site to meet the individual qualifying conditions; before site characterization, that ability is determined largely by examining the balance between those conditions along with information on the repository system. The

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identification of the favorable and potentially adverse conditions as present or not present at the site is based on data currently existing for the site or conservative assumptions when the existing data are inadequate for the identification. (Conservative assumptions are assumptions that minimize the possibility that later findings will prove the assumptions to be wrong.) In order for a favorable condition to be claimed as present, it is necessary for the existing data to clearly support that conclusion. Otherwise, the favorable condition is stated to be not present. Similarly, a potentially adverse condition is stated to be present unless the existing data and the conservative assumptions clearly support a conclusion that the condition is not present.

The process of making suitability evaluations and arriving at findings for the disqualifying and qualifying conditions is fully discussed and presented in the guideline-by-guideline evaluations in sections 6.2 and 6.3. The evidence required to support these evaluations includes the types of information specified in Appendix IV of the guidelines.

6.1.3 DIVISION OF THE GUIDELINES INTO CATEGORIES

The Nuclear Waste Policy Act of 1982 (the Act) (NWPA, 1983) requires two separate evaluations of the suitability of a site:

1. An evaluation as to whether a site is suitable for site characterization under the siting guidelines.

2. An evaluation as to whether a site is suitable for development as a repository under each guideline that does not require site characterization as a prerequisite for its application.

For making these two evaluations, the guidelines are divided into two categories according to whether they do or do not require site characterization as a prerequisite for their application. The basis for this division of the guidelines is the definition of site characterization in the Act. The Act defines site characterization essentially as activities undertaken to establish the geologic conditions at a candidate site, including borings, surface excavations, the sinking of exploratory shafts, and in-place testing at repository depth.

Therefore, in accordance with this definition, the guidelines requiring site characterization as a prerequisite to their application are those that contribute to establishing the geologic conditions at a site. The guidelines in this category are concerned predominantly with subsurface conditions, and most of them are postclosure guidelines. Section 6.3 presents the evaluations of the site against the guidelines in this category. The information required to establish compliance with these guidelines will be obtained during site characterization.

The guidelines not requiring site characterization as a prerequisite to application are those that do not contribute to establishing the geologic conditions at a site. The guidelines in this category are predominantly

concerned with surface conditions, and most of them are preclosure guidelines. The information required to establish compliance with these guidelines may be obtained before or during site characterization. Section 6.2 presents the evaluations of the site against the guidelines in this category.

Table 6-1 lists the guidelines in each category and shows the levels of findings that were made in accordance with Appendix III of the guidelines.

6.1.4 FORMATS FOR THE PRESENTATION OF SITE EVALUATIONS

In sections 6.2 and 6.3, the presentation of each technical guideline begins with an introduction that states the qualifying condition for that guideline and briefly explains the objectives and the structure of the guideline. The introduction is followed by a section that reviews or cites the data available for the evaluations against the guideline, explains the general assumptions that must be made, and discusses the uncertainties in the data. Each favorable, potentially adverse, and disqualifying condition is then discussed in turn; each discussion evaluates the presence or absence of the condition and states a conclusion based on that evaluation. Finally, the ability of the site to meet the qualifying condition is examined, and a conclusion is presented. For the disqualifying and qualifying conditions, the conclusion is presented as a finding at one of the levels specified by Appendix III of the guidelines (Section 6.1.2).

The format for presenting the system guidelines is similar, but it omits the discussion of favorable, potentially adverse, and disqualifying conditions because none of these conditions appear in the system guidelines.

The conclusions drawn in these presentations are different in Section 6.2 and in Section 6.3. Because the guidelines in Section 6.2 do not require site characterization, the conclusion refers to the suitability of the site for development as a repository. Such a conclusion cannot be drawn for guidelines that require site characterization as a prerequisite for their application; only after site characterization can the question of suitability for repository development be addressed. Rather, the appropriate conclusion for these guidelines is whether the site is suitable for further study. The conclusions presented in Section 6.3, therefore, refer only to the suitability of the site for characterization.

Table 6-1. Level of finding for qualifying and disqualifying conditions

Guideline	Level of finding for disqualifying condition[a]	Level of finding for qualifying condition[b]
POSTCLOSURE GUIDELINES		
960.4-1 Postclosure System	NA[c]	3
960.4-2-1 Geohydrology	1	3
960.4-2-2 Geochemistry	NA	3
960.4-2-3 Rock characteristics	NA	3
960.4-2-4 Climatic changes	NA	3
960.4-2-5 Erosion	1	3
960.4-2-6 Dissolution	2	4
960.4-2-7 Tectonics	1	3
960.4-2-8 Human interference		
960.4-2-8-1 Natural resources		
Condition 1	1	3
Condition 2	1	3
960.4-2-8-2 Site ownership and control	NA	3
PRECLOSURE GUIDELINES		
960.5-1 Preclosure System		
Radiological safety	NA	3
Environment, socioeconomics, and transportation	NA	3
Ease and cost of siting, construction operation, and closure	NA	3
960.5-2-1 Population density and distribution		3
Condition 1	2	
Condition 2	2	
Condition 3	1	
960.5-2-2 Site ownership and control	NA	3
960.5-2-3 Meteorology	NA	3
960.5-2-4 Offsite installations and operations	1	3
960.5-2-5 Environmental quality		3
Condition 1	1	
Condition 2	1	
Condition 3	1	
960.5-2-6 Socioeconomic impacts	1	3
960.5-2-7 Transportation	NA	3
960.5-2-8 Surface characteristics	NA	3
960.5-2-9 Rock characteristics	1	3
960.5-2-10 Hydrology	1	3
960.5-2-11 Tectonics	1	3

[a]Unless otherwise noted, the guideline has only one disqualifying condition.
[b]Each guideline has only one qualifying condition.
[c]NA - Not applicable; guideline has no disqualifying condition.

6.2 SUITABILITY OF THE YUCCA MOUNTAIN SITE FOR DEVELOPMENT AS A REPOSITORY: EVALUATION AGAINST THE GUIDELINES THAT DO NOT REQUIRE SITE CHARACTERIZATION

This section presents preliminary evaluations of the Yucca Mountain site against the eight technical guidelines and the two system guidelines that do not require data from site characterization as a prerequisite to their application. The technical guidelines are discussed first.

6.2.1 TECHNICAL GUIDELINES

Seven preclosure technical guidelines and one postclosure guideline are evaluated in this section. The qualifying condition for each technical guideline is presented at the beginning of the discussion of the guideline; it provides a framework for discussion of the associated favorable and potentially adverse conditions. An introduction describes the objective of the guideline and then refers the reader to a summary table that states the entire guideline, the conclusions for each favorable and potentially adverse condition, and the preliminary evaluation of the qualifying condition. For the disqualifying conditions associated with these technical guidelines, a separate summary table and text summaries are presented in Section 2.3. In this chapter, after a description of the sources of relevant data, a series of detailed evaluations provide the basis for the determination of whether each favorable or potentially adverse condition is present or not present at the Yucca Mountain site. Finally, the evaluation and conclusion for the qualifying condition summarize the favorable and potentially adverse conditions, as well as introduce any other information that supports the finding for the qualifying condition.

6.2.1.1. Postclosure site ownership and control (10 CFR 960.4-2-8-2)

6.2.1.1.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR Part 60, ownership, surface and subsurface rights, and control of access that are required in order that potential surface and subsurface activities at the site will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.

This site ownership and control technical guideline is a subpart of the postclosure human interference technical guideline. The objective of this guideline is to ensure that the U.S. Department of Energy obtains land ownership, in accordance with the requirements of 10 CFR 60.121 (1983), in order to establish passive controls following closure of the repository and thus decrease the likelihood of future human activities that would compromise the integrity of the repository. Passive controls include permanent markers on

the surface above the underground portion of the repository and records available to future generations.

The postclosure site ownership and control guideline consists of one favorable condition, one potentially adverse condition, and one qualifying condition. The evaluations against these conditions are summarized in Table 6-2.

6.2.1.1.2 Data relevant to the evaluation

The Yucca Mountain site is wholly on federally owned land. However, as explained below, three different agencies currently have jurisdiction and control over portions of the site. The eastern portion of the site is within the boundaries of the Nevada Test Site (NTS) under the control of the U.S. Department of Energy (DOE). The northwestern portion is on the Nellis Air Force Range (NAFR) under the control of the Department of the Air Force (DAF). The southwestern portion is on land in the public domain under the jurisdiction of the Bureau of Land Management (BLM) of the Department of the Interior (DOI). Figure 3-1 shows the location of these segments. If land is acquired and a repository is built at Yucca Mountain, a system of markers as described by Kaplan (1982) could be installed to prevent potential human interference with the repository.

Nevada Test Site segment

Pursuant to Public Land Order 2568, December 19, 1961, (DOI, 1961) this land has been withdrawn from all forms of appropriation under the public land laws, including the mining laws, and is under the jurisdiction and control of the DOE. The DOI has jurisdiction and control over "the mineral resources and mineral and vegetable materials" of the land. The DOE has control over all other surface and subsurface rights, including water rights from points of extraction on the land. The private acquisition of any surface or subsurface rights is presently precluded by virtue of the current public land order.

Nellis Air Force Range segment

Withdrawal legislation for the entire NAFR is currently before Congress. Until such time as this legislation is enacted, the BLM serves as the official protector of the land and custodian of all surface and subsurface rights. Private acquisition of any rights on or in the land is presently precluded pursuant to Section 204 of the Federal Land Policy and Management Act of 1976.

Bureau of Land Management segment

All land in this segment is in the public domain under the jurisdiction and management of the BLM and has not been segregated from the operation of the public land laws.

Table 6-2. Summary of analyses for Section 6.2.1.1; postclosure site ownership and control (10 CFR 960.4-2-8-2)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITION	
Present ownership and control of land and all surface and subsurface rights by the DOE.	The evidence indicates that this favorable condition is not present at Yucca Mountain: the DOE presently does not exercise jurisdiction and control over all the land that would make up the site.
POTENTIALLY ADVERSE CONDITION	
Projected land-ownership conflicts that cannot be successfully resolved through voluntary purchase-sell agreements, nondisputed agency-to-agency transfers of title, or Federal condemnation proceedings.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: withdrawal action would have been taken prior to constructing the proposed repository. Additional withdrawals or transfers would not be necessary for the postclosure period.
QUALIFYING CONDITION	
The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR Part 60, ownership, surface and subsurface rights, and control of access that are required in order that potential surface and subsurface activities at the site will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.	Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): all land in question is now owned by the Federal government; the portions of the site not presently under DOE jurisdiction are under the jurisdiction and control of the U.S. Department of the Air Force and the Bureau of Land Management. The DOE plans to obtain control through interagency transfer. Future site activities are not likely to cause radionuclide releases in excess of allowable limits.

All the above lands are currently free and clear of encumbrances arising under lease, right of entry, deed, patent, mortgage, appropriation, prescription, or otherwise (Gutsey and Nichols, 1972). The land use and withdrawal actions necessary for site characterization and for developing a geologic repository are described in a plan developed by the Nevada Nuclear Waste Storage Investigations Project (Richards and Vieth, 1983). The plan outlines the actions necessary for land acquisition to meet the requirements of 10 CFR 60.121 (1983).

Assumptions and data uncertainties

Uncertainties about the site ownership and control are related to interagency negotiations involving the DAF and BLM over land withdrawal and restrictions. Although the DOE has control over water rights from points of extraction on the NTS, it is possible that superior rights to the water in the same underground source may exist with respect to some point of extraction outside the NTS boundaries.

6.2.1.1.3 Favorable condition

Present ownership and control of land and all surface and subsurface rights by the DOE.

Evaluation

Control of the land where the proposed site is located currently resides with the U.S. Department of Energy (DOE) (the Nevada Test Site portion), the U.S. Department of the Air Force (DAF) (the Nellis Air Force Range portion), and the Bureau of Land Management (BLM). Permanent withdrawal and reservation of jurisdiction and control over surface and subsurface rights requires Congressional approval. This transfer could be implemented as described in the above-mentioned Nevada Nuclear Waste Storage Investigations Project plan for land use and withdrawal.

Conclusion

Presently, the DOE exercises jurisdiction and control over only a portion of the Yucca Mountain site; the remaining portions are under the jurisdiction and control of the DAF and the BLM. Therefore, the evidence indicates that this favorable condition is not present at Yucca Mountain. However, because the remaining portions of the proposed site are owned by the Federal Government, it is expected that, at a later date, the DOE can acquire jurisdiction and control over the land, including all surface and subsurface rights.

6.2.1.1.4 Potentially adverse condition

Projected land-ownership conflicts that cannot be successfully resolved through voluntary purchase-sell agreements, nondisputed agency-to-agency transfers of title, or Federal condemnation proceedings.

Evaluation

While one portion of the Yucca Mountain site lies within the Nevada Test Site (NTS) and already is under the jurisdiction and control of the U.S. Department of Energy (DOE), the site also includes tracts of land under the jurisdiction of the U.S. Department of the Air Force (DAF) and the Bureau of Land Management (BLM). The air space above the DAF portion is a small, remote section of the Nellis Air Force Range (NAFR) which is used only as a flight corridor for military aircraft, and the BLM portion is a tract immediately adjacent to the already restricted lands of the NAFR and the NTS on which no other activities are presently occurring and no privately held rights or encumbrances have been identified as existing. Withdrawal of the BLM portion from the public domain and transfer of control over the DAF portion would have been accomplished prior to construction of the proposed repository in order for the DOE to obtain jurisdiction and control over the entire site (Richards and Vieth, 1983).

Conclusion

Withdrawal action necessary for the DOE to obtain jurisdiction and control over a portion of the site is planned to be accomplished prior to the construction of the proposed repository. No additional land withdrawal action will be necessary for the postclosure period. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain. However, in view of the absence of conflicts over land use for the lands to be withdrawn before repository construction would begin, no impediments to the obtaining of control by the DOE are projected.

6.2.1.1.5 Evaluation and conclusion for the qualifying condition on the postclosure site ownership and control guideline

Evaluation

Control of the Yucca Mountain site presently resides with the U.S. Department of Energy (DOE), the Bureau of Land Management (BLM), and the U.S. Department of the Air Force (DAF). The Nevada Nuclear Waste Storage Investigations Project has prepared a plan for land use and withdrawal actions for the DOE to acquire jurisdiction over the necessary land from the BLM and the DAF. No existing privately held rights or encumbrances, which would necessitate government purchase or condemnation action, have been identified for any portion of the site. The implementation of Congressional action necessary for permanent transfer to the DOE has been deferred pending selection of the site for a repository. Once the land is under DOE jurisdiction, the DOE would be able to control access to it. Permanent markers would be used to mark the controlled area, which extends horizontally no more than 5 kilometers (3.1 miles) in any direction from the boundary of the underground facility and subsurface area committed to the repository. A permanent marker and information system could use four types of messages: (1) an obvious notification to possible intruders that something is located there; (2) a warning that what is located at the site is dangerous (e.g., the symbol for radioactive material); (3) basic information such as what actions must be avoided, what is located at the site, who placed it there, and where

to find additional information; and (4) a full record of information, such as plans, drawings, and environmental impact statements (Kaplan, 1982). The markers and records would be used to discourage future generations from deliberately or inadvertently disturbing the Yucca Mountain site after closure.

Conclusion

The plan by which the DOE would acquire jurisdiction and control over all surface and subsurface rights for the Yucca Mountain site will be implemented if the site is selected for a repository. No impediments to eventual complete ownership and control by the DOE have been identified. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for postclosure site ownership and control (level 3).

6.2.1.2 Population density and distribution (10 CFR 960.5-2-1)

6.2.1.2.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall be located such that, during repository operation and closure, (1) the expected average radiation dose to members of the public within any highly populated area will not be likely to exceed a small fraction of the limits allowable under the requirements specified in Section 960.5-1(a)(1), and (2) the expected radiation dose to any member of the public in an unrestricted area will not be likely to exceed the limit allowable under the requirements specified in Section 960.5-1(a)(1).

The population density and distribution technical guideline is one of four preclosure guidelines concerned with preclosure radiological safety. The objective of the guideline is to ensure the selection of a repository site that will minimize the risk to the public and permit compliance with the U.S. Environmental Protection Agency and the Nuclear Regulatory Commission regulations.

The guideline consists of two favorable conditions, two potentially adverse conditions, three disqualifying conditions, and one qualifying condition. The Yucca Mountain site is evaluated with respect to all these conditions in the following sections, and Table 6-3 summarizes the pertinent findings for all conditions except the disqualifying conditions.

6.2.1.2.2 Data relevant to the evaluation

This section presents data on population and population density, approximate distances from the proposed location of the surface facilities (measured in a straight line, not along existing road networks, on maps in the Nevada Map Atlas, State of Nevada, Department of Transportation, ca. 1984) and information on potential radiation doses to members of the public.

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Table 6-3. Summary of analyses for Section 6.2.1.2; population density and distribution (10 CFR 960.5-2-1)

Condition	Department of Energy (DOE) finding

FAVORABLE CONDITIONS

(1) A low population density in the general region of the site.

The evidence indicates that this favorable condition is present at Yucca Mountain: the site is located in a county with a population density of 0.5 person per square mile; the population density in the near-by areas is well below the continental U.S. average.

(2) Remoteness of the site from highly populated areas.

The evidence indicates that this favorable condition is present at Yucca Mountain: the proposed location of the surface facilities at Yucca Mountain is remote from the nearest highly populated area, which is about 137 kilometers (85 miles) away.

POTENTIALLY ADVERSE CONDITIONS

(1) High residential, seasonal, or daytime population density within the projected site boundaries.

The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: there is no seasonal, daytime, or residential population within the projected site boundaries.

(2) Proximity of the site to highly populated areas, or to areas having at least 1,000 individuals in an area 1 mile by 1 mile as defined by the most recent decennial count of the U.S. census.

The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: the nearest area 1 mile by 1 mile having a population of at least 1,000 is about 137 kilometers (85 miles) from the proposed location of the surface facilities.

Table 6-3. Summary of analyses for Section 6.2.1.2; population density and distribution
(10 CFR 960.5-2-1) (continued)

Condition	Department of Energy (DOE) finding
QUALIFYING CONDITION	
The site shall be located such that, during repository operation and closure, (1) the expected average radiation dose to members of the public within any highly populated area will not be likely to exceed a small fraction of the limits allowable under the requirements specified in Section 960.5-1(a)(1), and (2) the expected radiation dose to any member of the public in an unrestricted area will not be likely to exceed the limit allowable under the requirements specified in Section 960.5-1(a)(1).	Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): the site is in an area of extremely low population density; radiation doses are not expected to exceed a small fraction of the limits specified for members of the public in unrestricted areas.

In 10 CFR 960.2 (1984), a highly populated area is defined as, "Any incorporated place (recognized by the decennial reports of the U.S. Bureau of the Census) of 2,500 or more persons, or any census designated place (as defined and delineated by the Bureau) of 2,500 or more persons, unless it can be demonstrated that any such place has a lower population density than the mean value for the continental United States. Counties or county equivalents, whether incorporated or not, are specifically excluded from the definition of "place" as used herein." For purposes of his analysis, the mean population density of the continental United States is 76 persons per square mile, as shown in the 1985 Statistical Abstract of the United States (DOC, 1984) for the conterminous United States in 1980.

Nye County, where the Yucca Mountain site is located, had a 1980 population density of 0.5 person per square mile (Section 3.6.2.2). Gabbs, the only incorporated city in Nye County in 1980, had a population of 811 (DOC, 1981), and is located about 248 kilometers (154 miles) northwest of the proposed location of the surface facilities. Tonopah, the only census designated place in the county in 1980, had a population of 1,952. It is located about 153 kilometers (95 miles) to the northwest. There are no residential inhabitants within a 10-kilometer (6.2-mile) radius of the Yucca Mountain site; and all land within this radius is currently federally controlled and not open to settlement. Population values for Nye County communities nearest the Yucca Mountain site were not reported at the community level by the 1980 census. Estimates of their population values as reported in Smith and Coogan (1984), are discussed below. Their approximate distances (in a straight line, not along existing road networks) from the proposed location of the surface facilities are also given.

The nearest population center is located in the unincorporated Town of Amargosa Valley, residents of which are spread out in numerous small settlements within its estimated 1,036 square kilometers (400 square miles) (Section 3.6.4.1.1). Major population concentrations are located in the community formerly called Lathrop Wells, and now also called Amargosa Valley, approximately 23 kilometers (14 miles) to the south; the Amargosa Farm area, approximately 37 kilometers (23 miles) to the south; and the American Borate housing complex roughly 45 kilometers (28 miles) to the south. Population of these areas in 1984 was estimated to be 45, 1,500, and 280, respectively (Smith and Coogan, 1984). An estimate of the total population of the unincorporated town is not available (Section 3.6.2.2).

Beatty, located about 31 kilometers (19 miles) to the northwest had a 1984 estimated population of 800 (Smith and Coogan, 1984). Pahrump's 1984 population was estimated to be 5,500 (Smith and Coogan, 1984). It is located slightly more than 80 kilometers (50 miles) to the southeast.

Two rural counties adjacent to Nye County are Esmeralda and Lincoln. Their boundaries are located approximately 68 kilometers (42 miles) and 48 kilometers (30 miles) west and east, respectively, from the proposed location of the surface facilities. The 1980 population density of Esmeralda County was 0.2 person per square mile, and that of Lincoln was 0.4 person per square mile (DOC, 1981). There were no incorporated cities or census designated places in Esmeralda County in 1980. The incorporated city of Caliente in Lincoln County had a 1980 population of 982. Lincoln County had no census designated places in 1980 (DOC, 1981).

Clark County, adjacent to the southeast part of Nye County (with a boundary about 48 kilometers (30 miles) east of the proposed location of the surface facilities), had a 1980 population density of 58.8 persons per square mile (Section 3.6.2.3). The nearest urban area is the Las Vegas Valley in Clark County. It includes the incorporated cities of Henderson, Las Vegas, and North Las Vegas, and the unincorporated towns and communities of East Las Vegas, Enterprise, Grand View, Lone Mountain, Paradise, Spring Valley, Sunrise Manor, and Winchester. The 1980 population density of the Las Vegas Valley was 585 persons per square mile. The Las Vegas Valley is approximately 137 kilometers (85 miles) (as measured from the intersection of U.S. Highway 95 and Interstate 15) from the proposed location of the surface facilities. The remainder of Clark County outside the Las Vegas Valley makes up about 90 percent of its geographic area. This part of the county had a 1980 population density of 2.7 persons per square mile (Section 3.6.2.3). The unincorporated town of Indian Springs, located along U.S. Highway 95 in northwest Clark County, is approximately 74 kilometers (46 miles) from the proposed location of the surface facilities, making it the nearest Clark County community. Its 1980 population was estimated to be 1,446 (Section 3.6.2.3).

Sections 3.6.2.2 and 3.6.2.3 present a discussion of the recent and forecast baseline populations for Nye and Clark counties, respectively, and give recent population data for communities nearest the site. Note however, that distances reported in those sections are measured along the existing road network.

The Nevada Test Site (NTS) and Nellis Air Force Range (NAFR) surround the Yucca Mountain site on three sides. About 5,200 persons work but do not reside at the NTS, and several hundred may occasionally remain overnight in Mercury and other NTS locations; however, there are no permanent residences or private property on the NTS or NAFR. The southwest side of the Yucca Mountain site is bounded by land controlled by the Bureau of Land Management and is closed to permanent settlement but open to public access.

The potential radiation doses for the public residing within 80 kilometers (50 miles) of the repository site have been estimated for postulated accidents during repository operations (Jackson et al., 1984). The population within 80 kilometers (50 miles) of the proposed repository location was conservatively estimated to be 19,908, by identifying the counties within that radius and dividing the 1980 county population by the county area to obtain the county population density. Once county population densities were determined, the county area within the 80-kilometer (50-mile) radius was multiplied by that county's density to estimate population. The results for each county were then summed. If population centers (i.e., cities or unincorporated places) are accounted for, the population within 80 kilometers (50 miles) of the proposed repository is estimated to be 11,674 (Morales, 1985). The worst-case accident-related single exposure to the maximally exposed individual, assumed to be located approximately 4 kilometers (2.5 miles) southwest of the surface facilities was estimated to be 0.055 rem (0.068 rem 50-year dose commitment). The same accident would result in an estimated worst-case population dose commitment of 110 man-rem to a population of 19,908 within 80 kilometers (50 miles) of the repository site. Using estimates of natural radiation in granite from DOE (1980a), an estimate of the release of natural radioactivity from the volcanic rocks of the Yucca

Mountain site during construction can be calculated. Construction of a repository would resul. in an annual effective whole-body dose for a member of the general population of less than 0.05 millirem. Natural background radiation from all sources contributes an individual whole-body equivalent dose of 0.09 rem per year (Jackson et al., 1984). For a discussion of applicable dose limits, refer to sections 6.2.2.1 and 6.4.1. For discussions of potential operational radiation exposures, see Section 5.4.1.

Assumptions and data uncertainties

Long-term changes in population density and distribution are difficult to predict. For example, increased employment opportunities at the Yucca Mountain site during repository construction, operation, and decommissioning could result in population increases in the nearby towns that are different than recent settlement patterns of NTS workers (Table 5-26). However, actual settlement patterns would be one element of a socioeconomics monitoring program that would be developed.

6.2.1.2.3 Favorable conditions

(1) A low population density in the general region of the site.

Evaluation

The Yucca Mountain site is in Nye County, which had a 1980 population density of 0.5 person per square mile (Section 3.6.2.2). This is low in comparison with the 1980 population density of the continental United States, which was 76 persons per square mile. Two counties adjacent to central Nye County, west and east of the site, respectively, are Esmeralda and Lincoln. In these counties the 1980 population densities were 0.2 and 0.4 person per square mile, respectively (DOC, 1981).

Clark County had a 1980 population density of 58.8 persons per square mile. The nearest urban area is the Las Vegas Valley, 137 kilometers (85 miles) to the southeast. This area includes the incorporated cities of Henderson, Las Vegas, and North Las Vegas as well as the unincorporated towns and communities of East Las Vegas, Enterprise, Grandview, Lone Mountain, Paradise, Spring Valley, Sunrise Manor, and Winchester. The Las Vegas Valley had a 1980 population density of 585 persons per square mile. The part of Clark County outside the Las Vegas Valley, about 90 percent of its geographic area, had a 1980 population density of about 2.7 persons per square mile.

Conclusion

The county containing the Yucca Mountain site had a population density of 0.5 person per square mile, which is substantially below the continental U.S. average density of 76 persons per square mile. Two adjacent counties also had population densities well below the U.S. average. Outside the Las Vegas Valley, which is 137 kilometers (85 miles) away, Clark County had a population density of about 2.7 persons per square mile. Therefore, this favorable condition is present at Yucca Mountain.

8 0 0 0 8   0 5 4 0

(2)   Remoteness of the site from highly populated areas.

Evaluation

The Yucca Mountain site is in southern Nye County, Nevada (see Figure
3-21). Southern Nye County is bordered on the east by Clark and Lincoln
counties and on the west by Esmeralda County. Borders of these counties are
about 68 to 48 kilometers (42 to 30 miles) from the proposed location of the
surface facilities. In 1980, neither Lincoln County nor Esmeralda County
contained any highly populated areas. Since neither the incorporated city
(Gabbs) nor the census designated place (Tonopah) in Nye County had popu-
lations greater than or equal to 2,500 in 1980, neither are considered highly
populated areas for purposes of the evaluation of this guideline. Gabbs is
about 248 kilometers (154 miles) to the northwest, and Tonopah is about
153 kilometers (95 miles) to the northwest. The incorporated city of
Caliente in Lincoln County is not considered a highly populated area. The
nearest highly populated area is the Las Vegas Valley in Clark County,
approximately 137 kilometers (85 miles) southeast of the proposed location of
the surface facilities.

The unincorporated towns of Amargosa Valley and Beatty lie closest to
the Yucca Mountain site, at distances of 23 kilometers (14 miles, at the
nearest population concentration) and 31 kilometers (19 miles), respectively.
U.S. Bureau of the Census population estimates for these towns are not
available. Beatty had an estimated population of 800 (Smith and Coogan,
1984). Approximately 45 people were concentrated along U.S. Highway 95 in
the Amargosa Valley community formerly called Lathrop Wells; another 1,500
persons were located about 37 kilometers (23 miles) south of U.S. Highway 95
in the Amargosa Farm area; and approximately 280 persons lived at the
American Borate housing complex on Nevada State Route 373 about 45 kilometers
(28 miles) south of the surface facilities location (population data from
Smith and Coogan, 1984). These are not considered highly populated areas.

Conclusion

The Yucca Mountain site is remote from any highly populated area. The
nearest highly populated area is about 137 kilometers (85 miles) to the
southeast of the proposed location of the surface facilities. Therefore,
this favorable condition is present at Yucca Mountain.

6.2.1.2.4   Potentially adverse conditions

(1)   High residential, seasonal, or daytime population density
within the projected site boundaries.

Evaluation

The surface facilities for a repository at Yucca Mountain would be
located in the center of an uninhabited area with a radius of at least
10 kilometers (6.2 miles). Other than the work force currently engaged in
preliminary site investigations at Yucca Mountain as part of the Nevada

Nuclear Waste Storage Investigations Project, there is presently no daytime or seasonal use of the area.

Conclusion

The projected boundaries of the Yucca Mountain site (see Figure 2-1) presently contain no residential or daytime population, except for those daytime personnel associated with ongoing investigations of the site for a geologic repository. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(2) Proximity of the site to highly populated areas, or to areas having at least 1,000 individuals in an area 1 mile by 1 mile as defined by the most recent decennial count of the U.S. census.

Evaluation

The nearest highly populated area is the Las Vegas Valley about 137 kilometers (85 miles) to the southeast of Yucca Mountain. This is also the nearest area 1 mile by 1 mile having a population of at least 1,000 individuals (Clark County Department of Comprehensive Planning, 1983).

Conclusion

The Yucca Mountain site is about 137 kilometers (85 miles) away from the nearest highly populated area. It is equally remote from any area having at least 1,000 individuals in an area 1 mile by 1 mile as defined by the 1980 census. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

6.2.1.2.5 Disqualifying conditions

There are three disqualifying conditions with regard to population density and distribution. To avoid repetition, the disqualifying conditions (stated below) are evaluated together. Separate conclusions are given for each disqualifying condition.

A site shall be disqualified if:

(1) Any surface facility of a repository would be located in a highly populated area; or

(2) Any surface facility of a repository would be located adjacent to an area 1 mile by 1 mile having a population of not less than 1,000 individuals as enumerated by the most recent U.S. census; or

(3) The DOE could not develop an emergency preparedness program which meets the requirements specified in DOE Order 5500.3 (Reactor and Non-Reactor Facility Emergency Planning, Preparedness, and Response Program for Department of Energy

Evaluation

There are no residents within 10 kilometers (6.2 miles) of the Yucca
Mountain site. The nearest highly populated area is the Las Vegas Valley at
a distance of 137 kilometers (85 miles); this is also the distance to the
nearest area 1 mile by 1 mile with a population of more than 1,000 persons.

The U.S. Department of Energy (DOE) in cooperation with the State of
Nevada has produced an emergency preparedness plan and notification pro-
cedures (State of Nevada, Department of Human Resources, 1983; DOE/NVO, 1985)
that covers loss of control of radioactive materials leading to a hazard or
potential hazard to public health, safety, or property. This plan identifies
agencies and individuals to be notified in the event of a radiological emer-
gency. It provides guidance for the plan participants and establishes proce-
dures for requesting and providing assistance.

Conclusion for disqualifying condition 1

The nearest highly populated area is about 137 kilometers (85 miles)
from the proposed location of the surface facilities at Yucca Mountain.
Consequently, surface facilities at Yucca Mountain would not be located in a
highly populated area. Therefore, the evidence supports a finding that the
site is not disqualified on the basis of that evidence and is not likely to
be disqualified (level 2).

Conclusion for disqualifying condition 2

The Yucca Mountain site is not adjacent to any area 1 mile by 1 mile
having a population of 1,000 or more. The nearest such area is about
137 kilometers (85 miles) by air to the southeast. Therefore, the evidence
supports a finding that the site is not disqualified on the basis of that
evidence and is not likely to be disqualified (level 2).

Conclusion for disqualifying condition 3

Preparation of an emergency preparedness plan for Yucca Mountain should
present no problems; the DOE has already prepared such a plan for the Nevada
Test Site and has worked with the State of Nevada to establish a plan for the
State. Therefore, on the basis of the above evaluation, the evidence does
not support a finding that the site is disqualified (level 1).

6.2.1.2.6 Evaluation and conclusion for the qualifying condition on the
          population density and distribution guideline

Evaluation

The nearest highly populated area, according to 1980 census information,
is in the Las Vegas Valley of Clark County which is 137 kilometers (85 miles)
from the proposed location of the surface facilities at the Yucca Mountain

site. Preliminary calculations of radiation doses from worst-case single accidental exposure give a total-body dose of 0.055 (0.068 rem 50-year dose commitment) for the maximally exposed individual, who is assumed to be 4 kilometers (2.5 miles) from the surface facility (Jackson et al., 1984). For comparison, these doses are well below the dose limit from 10 CFR Part 20 (1984) of 0.5 rem per year for the total-body dose to a individual in an unrestricted area. The worst-case population dose for the same set of accidents is estimated at 110 man-rem to a conservatively estimated population of 19,908 within 80 kilometers (50 miles) of the potential repository site. The natural background sources contribute an individual total-body dose commitment of 0.09 rem per year and an annual whole-body population dose commitment of about 1,790 man-rem to the same 19,908 people (Jackson et al., 1984). Estimated releases under normal repository operations (for a generic repository) are shown in Section 6.4.1 to produce concentrations well below the maximum permissible concentrations.

Conclusion

The site is in an area of extremely low population density, remote from any highly populated areas. Normal repository operations are not expected to allow releases that exceed requirements. Preliminary calculations indicate that even the expected worst-case radiological dose will not exceed the limits of 10 CFR 960.5-1(a)(1) (1984) and will be negligible when compared with the background-radiation dose. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for population density and distribution (level 3).

6.2.1.3   Preclosure site ownership and control (10 CFR 960.5-2-2)

6.2.1.3.1   Introduction

The qualifying condition for this guideline is as follows:

The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR 60.121, ownership, surface and subsurface rights, and control of access that are required in order that surface and subsurface activities during repository operation and closure will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1).

This site ownership and control technical guideline is the second of four preclosure guidelines concerned with preclosure radiological safety. The objective is to ensure that the U.S. Department of Energy can obtain land ownership, in accordance with the requirements of 10 CFR 60.121 (1983), and minimize the risk of releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1).

The guideline consists of one favorable condition, one potentially adverse condition, and one qualifying condition. A summary of the evaluations presented below is given in Table 6-4.

Table 6-4. Summary of analyses for Section 6.2.1.3; preclosure site ownership and control
(10 CFR 960.5-2-2)

Condition	Department of Energy (DOE) finding

FAVORABLE CONDITION

Present ownership and control of land and all surface and subsurface mineral and water rights by the DOE.

The evidence indicates that this favorable condition is not present at Yucca Mountain: the DOE presently does not exercise jurisdiction and control over all of the land that would make up the site.

POTENTIALLY ADVERSE CONDITION

Projected land-ownership conflicts that cannot be successfully resolved through voluntary purchase-sell agreements, nondisputed agency-to-agency transfers of title, or Federal condemnation proceedings.

The evidence indicates that this potentially adverse condition is present at Yucca Mountain: withdrawal action is necessary in order for the DOE to obtain jurisdiction and control over a portion of the site.

QUALIFYING CONDITION

The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR 60.121, ownership, surface and subsurface rights, and control of access that are required in order that surface and subsurface activities during repository operation and closure will not be likely to lead to radionuclide release to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1).

Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): the portions of the site not presently under DOE jurisdiction are Federal land; the DOE has a plan to obtain control through interagency transfer. Surface and subsurface activities are unlikely to lead to radionuclide releases in excess of the regulatory limits.

6.2.1.3.2 Data relevant to the evaluation

The Yucca Mountain site is wholly on federally owned land not currently restricted by environmental land-use considerations. However, as explained below, three different agencies currently have jurisdiction and control over portions of the site. The eastern portion of the site is within the boundaries of the Nevada Test Site (NTS) under the control of the U.S. Department of Energy (DOE). The northwestern portion is on the Nellis Air Force Range (NAFR) under the control of the U.S. Department of the Air Force (DAF). The southwestern portion is on land in the public domain under the jurisdiction of the Bureau of Land Management (BLM) of the Department of the Interior (DOI). Figure 3-1 shows the location of these segments.

Nevada Test Site segment

Pursuant to Public Land Order 2568, December 19, 1961, (DOI, 1961) this land has been withdrawn from all forms of appropriation under the public land laws, including the mining laws, and is under the jurisdiction and control of the DOE. The DOI has jurisdiction and control over "the mineral resources and mineral and vegetable materials" of the land. The DOE has control over all other surface and subsurface rights, including water rights from points of extraction on the land. The private acquisition of any surface or subsurface rights is presently precluded by virtue of the current public land order.

Nellis Air Force Range segment

Withdrawal legislation for the NAFR is currently before Congress. Until such time as this legislation is enacted, the BLM serves as the official protector of the land and custodian of all surface and subsurface rights. Private acquisition of any rights on or in the land is presently precluded pursuant to Section 204 of the Federal Land Policy and Management Act of 1976.

Bureau of Land Management segment

All of this land is in the public domain under the jurisdiction and management of the BLM and has not been segregated from the operation of the public land laws.

All the above lands are currently free and clear of encumbrances arising under lease, right of entry, deed, patent, mortgage, appropriation, prescription, or otherwise (Lutsey and Nichols, 1972). The land use and withdrawal actions necessary for site characterization and for developing a geologic repository are described in a plan developed by the Nevada Nuclear Waste Storage Investigations Project (Richards and Vieth, 1983). The plan contains the actions necessary for land acquisition to meet the requirements of 10 CFR 60.121 (1983).

Assumptions and data uncertainties

Uncertainties about site ownership and control involve interagency negotiations with the DAF and the BLM over land withdrawal and restrictions. The DOE has control over water rights from points of extraction on the NTS. It

is possible that superior rights to the water in the same underground source may apply to a point of extraction located outside the NTS boundaries. The significance of this issue would depend on superior rights, and a comparison of the amount of water needed to construct and operate the repository to the amount available for extraction from the underground source. This issue will be resolved prior to the commencement of site characterization.

6.2.1.3.3 Favorable condition

Present ownership and control of land and all surface and subsurface mineral and water rights by the DOE.

Evaluation

Control of the land where the potential repository site is located currently resides with the U.S. Department of Energy (DOE) (the Nevada Test Site portion), the U.S. Department of the Air Force (DAF) (the Nellis Air Force Range portion), and the Bureau of Land Management (BLM). Permanent transfer of the required areas to the DOE, including all surface and subsurface rights, would require Congressional approval and could be implemented in accordance with the plan for land use and withdrawal prepared by the Nevada Nuclear Waste Storage Investigations Project.

Conclusion

Presently the DOE has jurisdiction over only a portion of the Yucca Mountain site; the remaining portions are controlled by the DAF and the BLM. Therefore, the evidence indicates that this favorable condition is not present at Yucca Mountain.

6.2.1.3.4 Potentially adverse condition

Projected land-ownership conflicts that cannot be successfully resolved through voluntary purchase-sell agreements, nondisputed agency-to-agency transfers of title, or Federal condemnation proceedings.

Evaluation

While one portion of the Yucca Mountain site lies within the Nevada Test Site (NTS) and already is under the jurisdiction and control of the U.S. Department of Energy, the site also includes tracts of land under the jurisdiction of the U.S. Department of the Air Force (DAF) and the Bureau of Land Management. The air space above the DAF portion is a small, remote section of the Nellis Air Force Range which is used as a flight corridor for military aircraft, and the BLM portion is a tract immediately adjacent to the already restricted lands of the NAFR and the NTS on which no other activities are presently occurring and no privately held rights or encumbrances have been identified as existing. Withdrawal of the BLM portion from the public domain and transfer of control over the DAF portion are necessary for the DOE to

obtain jurisdiction and control over the entire site (information from the land use and withdrawal action plan by Richards and Vieth (1983) cited in Section 6.2.1.3.2).

Conclusion

Withdrawal action is necessary for the DOE to obtain jurisdiction and control over the entire site. Therefore, the evidence indicates that this potentially adverse condition is present at Yucca Mountain. However, in view of the absence of conflicts over land use for this portion, no impediments to the obtaining of control by the DOE are projected.

6.2.1.3.5   Evaluation and conclusion for the qualifying condition on the preclosure site ownership and control guideline

Evaluation

Control of the Yucca Mountain site presently resides with the U.S. Department of Energy (DOE) (the eastern portion on the Nevada Test Site), the U.S. Department of the Air Force (DAF) (the northwestern portion on the Nellis Air Force Range), and the Bureau of Land Management (BLM) (the southeastern portion). The Nevada Nuclear Waste Storage Investigations Project developed a land use and withdrawal plan for the DOE to acquire jurisdiction over the necessary land from the BLM and DAF. No existing privately held rights or encumbrances, which would necessitate government purchase or condemnation action, have been identified for any portion of the site. The implementation of Congressional action necessary for the permanent transfer of title to the DOE has been deferred pending the selection of a site for a repository. A plan to control and limit access to the Yucca Mountain site during the operation and closure of a repository will be prepared in accordance with DOE policies and procedures limiting access to restricted areas. No problems are expected in meeting the applicable safety requirements for radioactive releases to unrestricted areas (Section 6.2.1.2.6).

Conclusion

The plan by which the DOE would acquire jurisdiction and control over all surface and subsurface rights for the Yucca Mountain site will be implemented if the Yucca Mountain site is selected for a repository. No impediments to eventual complete ownership and control by the DOE have been identified. Surface and subsurface activities during repository operation and closure are not expected to lead to releases exceeding the requirements specified in Section 960.5-1(a)(1). Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for preclosure site ownership and control (level 3).

6.2.1.4 Meteorology (10 CFR 960.5-2-3)

6.2.1.4.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall be located such that expected meteorological conditions during repository operation and closure will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1).

The meteorology technical guideline addresses the concern that radioactive material released during repository operations and closure could be transported to an unrestricted area. The principal objective of this preclosure guideline is to ensure that the meteorological conditions at the proposed site are favorable for the atmospheric dispersion of any airborne radionuclides that might be released from the repository and to ensure compliance with the system guideline for preclosure radiological safety. Also of concern is the potential for extreme weather phenomena that could affect the operation and safety of the repository.

The guideline consists of one favorable condition, two potentially adverse conditions, and one qualifying condition. The evaluations presented below are summarized in Table 6-5.

6.2.1.4.2 Data relevant to the evaluation

Long-term meteorological data have not been collected at Yucca Mountain. A weather station was operated from 1956 to 1978 at Yucca Flat, approximately 40 kilometers (25 miles) to the northeast. Data from the station have been compiled for the 10 years from 1962 through 1971 (Bowen and Egami, 1983), and upper air data have been compiled for the 7 years from 1957 through 1964 (Quiring, 1968). Since mid-1982, a meteorological measurement system consisting of two monitoring stations, one near the ridge and one to the east of Yucca Mountain (both instrumented at levels 10 and 3 meters (33 and 10 feet) above the ground, has been operated for the Nevada Nuclear Waste Storage Investigations Project by the Desert Research Institute. Data from this system are available (Church et al., 1984). The National Weather Service has been recording meteorological data since 1914 at Beatty, approximately 31 kilometers (19 miles) west of Yucca Mountain. These data are on file at the National Oceanic and Atmospheric Administration, National Climatic Center, Asheville, North Carolina.

Statistical information on severe weather and storms in southern Nevada is contained in reports by Thom (1963), Pautz (1969), the U.S. Nuclear Regulatory Commission (Henz and Pearl, 1981), Bowen and Egami (1983), Quiring (1983), and Hershfield (1961). Regional atmospheric diffusion and dispersion characteristics are discussed by Bowen and Egami (1983) and Holzworth (1972).

Table 6-5. Summary of analyses for Section 6.2.1.4; meteorology (10 CFR 960.5-2-3)

Condition	Department of Energy (DOE) finding

FAVORABLE CONDITION

Prevailing meteorological conditions such that any radioactive releases to the atmosphere during repository operation and closure would be effectively dispersed, thereby reducing significantly the likelihood of unacceptable exposures to any member of the public in the vicinity of the repository.

The evidence indicates that this favorable condition is present at Yucca Mountain: regional wind flow patterns and atmospheric dispersion characteristics are expected to effectively disperse radioactive releases, if any, and to thereby reduce the likelihood of unacceptable exposures to any member of the public.

POTENTIALLY ADVERSE CONDITIONS

(1) Prevailing meteorological conditions such that radioactive emissions from repository operation or closure could be preferentially transported toward localities in the vicinity of the repository with higher population densities than are the average for the region.

The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: surface and high-level winds toward the population center in the Las Vegas urban area (about 137 kilometers (85 miles) away by air) occur less than 12 percent of the time. No preferential transport toward local population centers is expected.

(2) History of extreme weather phenomena—such as hurricanes, tornadoes, severe floods, or severe and frequent winter storms—that could significantly affect repository operation or closure.

The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: Yucca Mountain has one of the lowest frequencies of extreme weather in the U.S. Extreme weather phenomena occurring in the desert are of such short duration that no significant effects on repository operation or closure are expected.

Table 6-5. Summary of analyses for Section 6.2.1.4; meteorology (10 CFR 960.5-2-3) (continued)

Condition	Department of Energy (DOE) finding
QUALIFYING CONDITION	
The site shall be located such that expected meteorological conditions during repository operation and closure will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1).	Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): good atmospheric dispersion and limited possibility for preferential transport toward population centers are expected; no severe meteorological conditions that would cause radionuclide releases greater than regulatory limits are expected.

Data regarding the population centers in the region around Yucca Mountain have been obtained from Smith and Coogan (1984) and Clark County Department of Comprehensive Planning (1983).

Assumptions and data uncertainties

Much of the available meteorological information is not specific to Yucca Mountain. However, the Yucca Flat and Beatty measurement stations are close enough for their data to be representative of the general meteorological conditions at Yucca Mountain. Also, both the Yucca Flat station and the proposed repository surface facilities are located in topographically similar basins, and should experience similar meteorological conditions. Terrain-induced diurnal wind flow patterns are very localized and would not contribute significantly to regional atmospheric dispersion. Upper level wind direction data should adequately reflect the regional-scale winds, which are primarily responsible for long-range transport. The historical information on severe weather and storms has been collected at a limited number of observation stations in the region; the frequency of these phenomena could be slightly underestimated, because of the broad spatial distribution of recording stations. Nonetheless, the frequency or severity of storms probably is not significantly underestimated because the observed frequencies are low throughout the area.

6.2.1.4.3 Favorable condition

Prevailing meteorological conditions such that any radioactive releases to the atmosphere during repository operation and closure would be effectively dispersed, thereby reducing significantly the likelihood of unacceptable exposures to any member of the public in the vicinity of the repository.

Evaluation

Meteorological conditions should provide for effective atmospheric dispersion at the Yucca Mountain site. It is assumed that regional scale patterns are similar to those measured at Yucca Flat. It is recognized that meteorological conditions vary somewhat with altitude and geographic location. High average annual wind speeds of 11.9 kilometers (7.4 miles) per hour have been measured at Yucca Flat over a 10-year period of record (Bowen and Egami, 1983), and high wind speeds, which favor effective dispersion, are also expected at Yucca Mountain. Calculations by Holzworth (1972) indicate that extreme limitations to atmospheric dispersion should rarely occur over the Yucca Mountain area. Isopleths of the mean annual mixing heights show that the region surrounding the proposed site experiences some of the deepest atmospheric mixing layers in the United States, a condition that is favorable to atmospheric mixing and dispersion.

Conclusion

Wind velocities, flow patterns, and atmospheric-diffusion characteristics in the region of the Yucca Mountain site will contribute to the

effective dispersion of airborne radionuclides. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

6.2.1.4.4 Potentially adverse conditions

(1) Prevailing meteorological conditions such that radioactive emissions from repository operation or closure could be preferentially transported toward localities in the vicinity of the repository with higher population densities than are the average for the region.

Evaluation

Because of the sparse distribution of cities and towns in southern Nevada, establishing a meaningful average population density is difficult. In addition, some of the small towns close to Yucca Mountain may experience population increases if the site is selected for development as a repository. For these reasons, it is prudent to assess the likelihood of preferential atmospheric transport toward the smaller nearby towns as well as the larger cities in the region. The nearest population center to Yucca Mountain is the unincorporated Town of Amargosa Valley, whose residents are spread out in numerous small settlements within its estimated 1,036 square kilometers (400 square miles) (Section 3.6.4.1.1). Major population concentrations are located in the community formerly called Lathrop Wells and now known as Amargosa Valley, approximately 23 kilometers (14 miles) to the south; the Amargosa Farm Area, approximately 37 kilometers (23 miles) to the south; and the American Borate housing complex roughly 45 kilometers (28 miles) to the south. Population of these areas in 1984 was estimated to be 45, 1,500, and 280, respectively (Smith and Coogan, 1984). An estimate of the total population in the unincorporated town is not available (see Section 3.6.2.2). The nearest highly populated area to Yucca Mountain is the Las Vegas Valley with a 1980 population of 443,730 (Clark County Department of Comprehensive Planning, 1983). It is located approximately 137 kilometers (85 miles) by air southeast of the site. The town of Beatty, with a population of 800 (Smith and Coogan, 1984), is approximately 31 kilometers (19 miles) by air west of the site.

Wind speed and direction data have been compiled for the station located at Yucca Flat for the period 1961-1978 (DOC, 1986). Although these data reflect terrain influences specific to Yucca Flat, the setting at Yucca Mountain is similar enough to warrant use of the Yucca Flat data for this analysis. The general north-south alignment of the basin in which the repository would be located will most likely be the major influence on surface wind patterns, as is the case for Yucca Flat. Winds from the south dominate the distribution, occurring 14 percent of the time on an annual basis. Winds from the north are also quite frequent, occurring just over 11 percent of the time, again on an annual basis. Seasonally, southerly winds are most common in the spring and summer months, shifting to a northerly dominance in fall and winter months. Northwest winds (which would transport material to the southeast toward Las Vegas) have occurred less than 10 percent of the time on the average. Winds that could transport material to the west toward Beatty have been observed only 5 percent of the time.

A 7-year record of upper-air data from Yucca Flat (Quiring, 1968) was used to further evaluate the meteorological conditions that might transport airborne radionuclides toward population centers. Wind-direction data from two heights, 1,500 and 1,800 meters (5,000 and 6,000 feet) above mean sea level, were used in this assessment. Data from these levels are considered to be indicative of atmospheric-transport winds beyond the influence of local terrain features (i.e., Yucca Mountain). At 1,500 meters (5,000 feet), winds from the entire northwest sector (285 to 345°), which could transport airborne radionuclides toward the Las Vegas Valley, occurred only 11 percent of the time annually. At 1,800 meters (6,000 feet), winds from the northwest were observed approximately 10 percent of the time annually. Winds from the east (which would transport material toward Beatty) occurred approximately 2 percent of the time at Yucca Flat at both 1,500 and 1,800 meters (5,000 and 6,000 feet). The wind blows toward the south approximately 20 percent of the time at the 1,500-meter (5,000-foot) level and 14 percent of the time at the 1,800-meter (6,000-foot) level.

Conclusion

Regional meteorological flow patterns will not cause the preferential transport of airborne radionuclides from the site toward localities with higher population densities than are the average for the region. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(2) History of extreme weather phenomena--such as hurricanes, tornadoes, severe floods, or severe and frequent winter storms--that could significantly affect repository operation or closure.

Evaluation

The severe weather recorded in the area of the Yucca Mountain site includes high winds, thunderstorms, tornadoes, hail, and sandstorms, but occurrences of these extreme weather phenomena are infrequent. Thunderstorms occur on 16 percent of the days in July and August, but only occur an average of 5 percent of the days annually at Yucca Flat (Bowen and Egami, 1983). Severe thunderstorms create a potential for flash flooding, but they generally do not last longer than an hour according to Bowen and Egami (1983). Discussions of the drainage control measures that are expected to provide adequate protection from flood damage for Yucca Mountain are included in sections 6.3.3.1 and 6.3.3.3. High winds may occur in the area, accompanying winter storm fronts or thunderstorms. Wind speeds in excess of 100 kilometers (60 miles) per hour can be expected to occur on a 100-year return period (Quiring, 1968). However, such velocities are not common; monthly average wind speeds for Yucca Flat do not deviate significantly from the average annual wind speed. See Section 3.4.3 for further discussion of weather conditions. Significant lightning strikes have averaged only 18 per year for the entire State of Nevada (Henz and Pearl, 1981). Tornadoes are very rare in Nevada, with the probability of a tornado striking Yucca Mountain calculated to be 7.5×10^{-4} per year or once in 1,333 years (Thom, 1963). Hail with a diameter of 1.9 centimeters (0.75 inch) or larger was observed on 7 days in Nevada between 1955 and 1967 (Pautz, 1969). Sandstorms are common in Nevada but rarely severe enough to be expected to affect

repository operation or closure. The annual average snowfall at Yucca Flat is 21 centimeters (8.3 inches) (Bowen and Egami, 1983). The statistical maximum 24-hour precipitation for 10- and 100-year storms for Yucca Flat is 38 and 57 millimeters (1.50 and 2.25 inches), respectively (Hershfield, 1961). Quiring (1983) provides more recent data for Yucca Flat on the 24-hour precipitation for 10- and 100-year events of 45 and 68 millimeters (1.8 and 2.7 inches), respectively. The above frequencies of occurrence of severe weather are among the lowest in the United States (Hershfield, 1961). Furthermore, the magnitudes of these phenomena are not unusually large.

Conclusion

Available statistical summaries reveal that the region surrounding Yucca Mountain has one of the lowest frequencies of extreme weather in the United States. Extreme weather phenomena are neither frequent enough nor severe enough to be expected to significantly affect the safety of repository operation or closure. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

6.2.1.4.5 Evaluation and conclusion for the qualifying condition on the meteorology guideline

Evaluation

Records of meteorological data for Yucca Flat and Beatty, combined with statistical evaluations of severe-weather phenomena, indicate that occurrences of severe weather are infrequent and would not be expected to significantly affect repository construction, operation, or closure. Deep atmospheric mixing in the region will contribute to the effective dispersion of airborne radionuclides if any are released from the repository. Prevailing wind directions are not likely to cause preferential transport of airborne radionuclides toward regional population centers. Extreme weather phenomena are rare in the vicinity of Yucca Mountain, except for occasional heavy precipitation of short duration that may cause localized flash flooding (Section 6.3.3.3). However, standard drainage control measures are considered adequate to ensure that the public health and safety are protected and that no radionuclide releases to an unrestricted area greater than those allowable under applicable regulations and standards are likely.

Conclusion

No severe meteorological conditions have been recorded or are expected to occur in the region that would contribute to radionuclide releases to an unrestricted area greater than those allowable under regulatory limits.

6.2.1.5 Offsite installations and operations (10 CFR 960.5-2-4)

6.2.1.5.1 Introduction

The qualifying condition for this guideline is as follows:

> The site shall be located such that present projected effects from nearby industrial, transportation, and military installations and operations, including atomic energy defense activities, (1) will not significantly affect repository siting, construction, operation, closure, or decommissioning or can be accommodated by engineering measures and (2), when considered together with emissions from repository operation and closure, will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1).

The offsite installations and operations technical guideline is the last of the four preclosure technical guidelines concerned with preclosure radiological safety. The objectives of this guideline are (1) to ensure that the impacts of any nearby industrial, transportation, military, and atomic energy defense installations and operations on repository siting, construction, operation, closure, and decommissioning are adequately considered and (2) to ensure that any radionuclide emissions from such installations when combined with preclosure emissions from the repository, would not lead to total radiological exposures in any unrestricted area in excess of regulatory limits.

This guideline consists of one favorable condition, two potentially adverse conditions, one disqualifying condition, and one qualifying condition. The evaluations presented below are summarized in Table 6-6.

6.2.1.5.2 Data relevant to the evaluation

The installations and operations adjacent to Yucca Mountain are the Nevada Test Site (NTS) on the east and the Nellis Air Force Range (NAFR) to the northwest. The primary mission of the NTS is the underground testing of nuclear devices. The size of nuclear tests is currently limited to a maximum yield of 150 kilotons by the Threshold Test Ban Treaty and the Treaty on Underground Nuclear Explosions for Peaceful Purposes (Vortman, 1979; ERDA, 1977), but the capability to return to larger or former yields must be retained. The number of announced nuclear tests has been averaging about 20 per year and is expected to remain at that level for the foreseeable future (DOE/NVO, 1983b). At present, tests are conducted at Yucca Flat, Rainier Mesa, and Pahute Mesa (Figure 6-1). The size of tests is restricted by the potential for damage to offsite facilities from ground motion; Yucca Flat has a yield limit of about 250 kilotons and Pahute Mesa has a 1,400-kiloton limit (Vortman, 1979). Both of these limits are well above the current yield limits specified by treaty. The Buckboard area, a past area of testing that may be used again, has a 700-kiloton yield limit (Vortman, 1979). The yield limit for Mid Valley, a future potential test area, is likely to be similar to that for Yucca Flat.

Table 6-6. Summary of analyses for Section 6.2.1.5; offsite installations and operations
(10 CFR 960.5-2-4)

Condition	Department of Energy (DOE) finding

FAVORABLE CONDITION

Absence of contributing radioactive releases from other nuclear installations and operations that must be considered under the requirements of 40 CFR Part 191, Subpart A.

The evidence indicates that this favorable condition is present at Yucca Mountain: there are no nuclear installations or operations regulated by 40 CFR Part 191 in the region.

POTENTIALLY ADVERSE CONDITIONS

(1) The presence of nearby potentially hazardous installations or operations that could adversely affect repository operation or closure.

The evidence indicates that this potentially adverse condition is present at Yucca Mountain: the potential exists for short-term interruptions of repository activities due to weapons tests and the remote possibility of interruptions or releases caused by an aircraft crash.

(2) Presence of other nuclear installations and operations subject to the requirements of 40 CFR Part 190 or 40 CFR Part 191, Subpart A, with actual or projected releases near the maximum value permissible under those standards.

The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: there are no nuclear installations or operations regulated by 40 CFR Part 190 or 40 CFR Part 191 in the area.

Table 6-6. Summary of analyses for Section 6.2.1.5; offsite installations and operations (10 CFR 960.5-2-4) (continued)

Condition	Department of Energy (DOE) finding
QUALIFYING CONDITION	
The site shall be located such that present projected effects from nearby industrial, transportation, and military installations and operations, including atomic energy defense activities, (1) will not significantly affect repository siting, construction, operation, closure, or decommissioning, or can be accommodated by engineering measures and (2), when considered together with emissions from repository operation and closure, will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1).	Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): the potential for short-term interruption of repository activities by weapons tests is not expected to significantly affect repository siting, construction, operation, closure, or decommissioning; releases from underground weapons testing when considered with potential repository emissions, will not be likely to exceed limits for radionuclide releases to unrestricted areas.
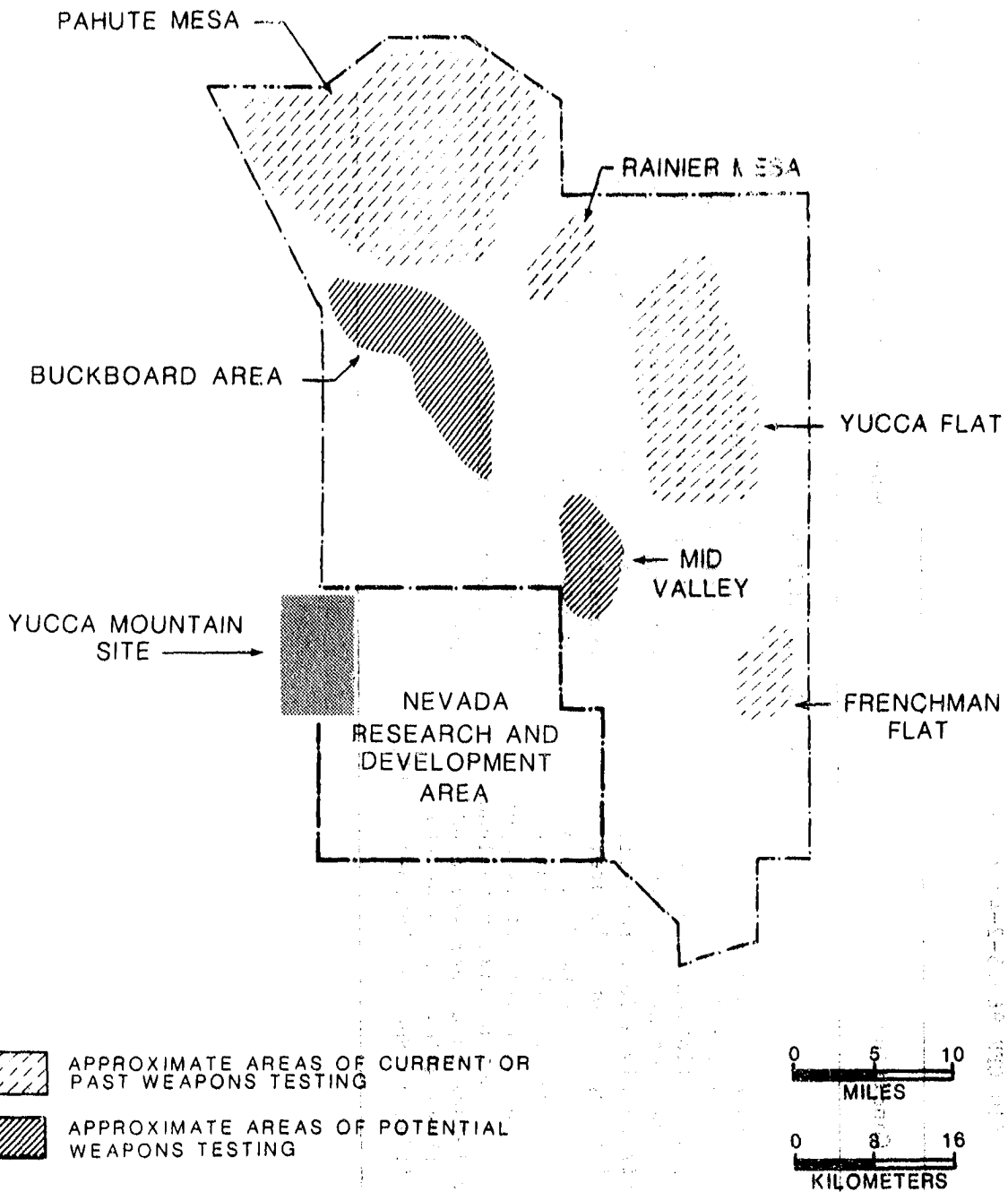
Figure 6-1. Past, current, and potential future weapons-testing areas on the Nevada Test Site.

Underground nuclear explosions generate seismic energy; the resulting ground motion is similar to that generated by natural earthquakes. The ground motion produced by underground nuclear explosions has been extensively investigated (ERC, 1974; Vortman, 1979, 1980, 1982, 1983; Vortman and Long 1982a,b). Because of a concern about offsite damage, equations have been developed to predict ground motion from underground nuclear explosions at Pahute Mesa and Yucca Flat, where nuclear tests are routinely conducted (ERC, 1974). These test areas are 40 to 50 kilometers (24 to 31 miles) north and east of Yucca Mountain.

Data from underground nuclear tests conducted since 1971 indicate that the major portion of radioactive emissions from underground nuclear tests are contained (ERDA, 1977). Onsite sampling for airborne tritium and noble gases shows that the average concentrations of tritium and xenon-133 are slightly higher than ambient offsite levels (Scoggins, 1983). The tritium enters the atmosphere by evaporation from soil moisture in and around past experimental areas, from holding ponds that receive water drained from tunnel areas, and from gas seepage. Xenon-133 may be released in small quantities as it seeps upward to the surface from underground detonation points. Postshot reentry drilling operations may release small quantities of radioactive noble gases. However, for four out of the last five 1-year reporting periods, no detectable levels of radioactivity from the underground nuclear-test program were observed by any of the monitoring networks located off the NTS (see discussion under the first potentially adverse condition). The radiological background information is reviewed in Section 3.4.7.

Available data describe upper limits to the radiation doses that accidents at the repository might cause. The potential worst-case accidental radiation dose for the public residing within 80 kilometers (50 miles) of the repository site and the worst-case dose commitment for repository personnel have been estimated (Jackson et al., 1984).

The Nevada Research and Development Area, adjacent to the eastern side of Yucca Mountain, is currently being used for research programs. A program that was evaluated for potential impact on repository construction and operation activities is being conducted at the Engine Maintenance, Assembly, and Disassembly facility (E-MAD). There are 17 spent nuclear fuel assemblies at the E-MAD facility which were used for tests and demonstrations that commenced in 1978. These assemblies are scheduled for removal in May and June of 1986. A detailed safety assessment was issued (DOE/NVO, 1978) identifying the engineered safety features, procedures, and site characteristics that (1) prevent the occurrence of potential accidents, or (2) ensure that the consequences of postulated accidents are either insignificant or adequately mitigated. Evaluations were made of the radiological impacts of normal operations, abnormal operations, and postulated accidents at the E-MAD facility. Analyses were also performed to determine the effects on nuclear criticality safety of the postulated accidents and credible natural phenomena. In the unlikely event of the postulated worst-case fuel-handling accident, the maximum total radiation exposure at the NTS boundary was estimated to be less than 0.001 rem. For comparison, this is well below the whole-body radiation dose limit in unrestricted areas of 0.5 rem per year prescribed by 10 CFR Part 20 (1984).

8 0 0 0 8   0 5 6 0

A commercial low-level waste burial site is located about 31 kilometers (19 miles) west of Yucca Mountain near Beatty. Radiation monitoring is conducted continuously at this site by the U.S. Environmental Protection Agency (Black et al., 1983).

The NAFR is used primarily for aerial bombing and gunnery practice. The Tonopah Test Range, an area of 1,615 square kilometers (600 square miles) in the northwestern part of the NAFR, is used by the DOE primarily for airdrop tests of ballistic shapes (ERDA, 1975). The portion of the range in the immediate vicinity of Yucca Mountain is used only for overflights and provides air access to the northwestern part of the range.

The DOE, through negotiations with the U.S Air Force (USAF), has established operational restrictions for flights through the air space controlled by the DOE over the NTS. Two small flight corridors were designated in the vicinity of Yucca Mountain. They are R4808W and R4808E. The proposed surface facilities complex will be located within the R4808W corridor. The proposed subsurface facilities will be located adjacent to the west side of the R4808W corridor. Currently R4808E is generally closed to all military aircraft, while R4808W is open to military aircraft upon request. The DOE is interacting with the U.S. Air Force (USAF) to address and resolve all concerns of potential repository impacts on USAF operations in the area. The DOE policy is not to restrict the flight requirements of the USAF operations.

Assumptions and data uncertainties

It is possible that future underground nuclear tests will be conducted on the NTS at locations other than Pahute Mesa, Rainier Mesa, and Yucca Flat. Two possible locations that have been identified are the Buckboard area, which is 23 to 37 kilometers (14 to 23 miles) from Yucca Mountain, and Mid Valley, which is 25 to 30 kilometers (16 to 19 miles) from Yucca Mountain. Vortman (1980) indicated that a given size underground nuclear test in the Buckboard area would produce about the same ground motion as would result from a test of the same size on Pahute Mesa because the rock properties that control ground motion are similar at the two locations. However, the ground motion that would result at Yucca Mountain from Buckboard area tests would be greater than that from tests at Pahute Mesa because the Buckboard area is closer to Yucca Mountain. Mid Valley and Yucca Flat are also likely to produce about the same ground motion from tests the same size. Similarly, tests conducted at Mid Valley would produce greater ground motion at Yucca Mountain than would be caused by tests of the same size at Yucca Flat because Mid Valley is closer to Yucca Mountain.

No new industrial or defense-related activities are planned in the vicinity of Yucca Mountain. The USAF is currently evaluating potential locations for deployment of small intercontinental ballistic missiles, in response to the recommendations of the President's Commission on Strategic Forces. Three modes of deployment are being considered: hard silos, hard mobile launchers with random movement, and hard mobile launchers in a confined area at existing minutemen complexes. The USAF is examining 51 sites in 14 states. Twenty-two of these sites are being considered for hard mobile launchers with random movement, six for mobile launchers in a confined area, and some sites of these two alternatives plus the remaining twenty-four

sites are being considered for hard silo deployment. The NTS is one of the sites currently under preliminary consideration for hard mobile launcher deployment. The USAF is presently evaluating that land area available at the Nevada Test Site for deployment of hardened mobile launchers that will not conflict with existing facilities or approved missions. Potential conflicts have been identified by the DOE and include: a mission conflict with nuclear testing and the DOE requirement to ensure availability of vast real estate indefinitely; a mission conflict with future Strategic Defense Initiatives research and development; and severe administrative conflicts on safety, security, scheduling of nuclear tests, communications, air space restrictions, resources, housing, transportation, and environmental issues. Additional information on the USAF site evaluation process is not expected until early 1986. At present, the limited amount of information available on which areas will be selected, the sites within those areas, and the extent of the land requirements required to support deployment make it impossible to evaluate impacts at this time.

6.2.1.5.3 Favorable condition

Absence of contributing radioactive releases from other nuclear installations and operations that must be considered under the requirements of 40 CFR 191, Subpart A.

Evaluation

Subpart A of 40 CFR Part 191 (1985) applies to radiation doses received by members of the public as a result of the management (except for transportation) and storage of spent nuclear fuel and high-level radioactive waste. The nuclear activities at the NTS are not controlled by Subpart A of 40 CFR Part 191 (1985).

Conclusion

No nearby nuclear installations or operations regulated by Subpart A of 40 CFR Part 191 (1985) exist in the region surrounding the Yucca Mountain site. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

6.2.1.5.4 Potentially adverse conditions

(1) The presence of nearby potentially hazardous installations or operations that could adversely affect repository operation or closure.

Evaluation

The portion of the Nellis Air Force Range (NAFR) near Yucca Mountain is used for military-aircraft flights to and from target areas, although this portion of the NAFR is not a target area. If a repository is built at Yucca Mountain, there may be low-altitude overflights by U.S. Air Force (USAF) air-

craft of trains transporting casks of waste on the proposed rail-spur access route to the site. The effect on a repository of overflights would be increased noise levels and a remote chance of an airplane crash at the site. The U.S. Department of Energy (DOE), through discussions with the USAF is evaluating the potential for possible conflicts between USAF and repository operations, including access routes. No irreconcilable conflicts have been identified in these discussions and a variety of options for minimizing conflicts have been discussed for consideration if further study indicates such actions are required.

The Nevada Research and Development Area adjacent to the eastern side of Yucca Mountain, is currently being used for research programs. There are 17 spent fuel assemblies at the Engine Maintenance, Assembly, and Disassembly (E-MAD) facility; they have been used for tests and demonstrations that began in 1978. These assemblies are scheduled for removal in May/June of 1986. A detailed safety assessment was issued (DOE/NVO, 1978) evaluating the radiological impacts of normal operations, abnormal operations, and postulated accidents at the E-MAD facility. Analyses were also performed to determine the effects on nuclear criticality safety of the postulated accidents and credible natural phenomena. In the unlikely event of the postulated worse-case fuel handling accident, the maximum total radiation exposure at the Nevada Test Site boundary was estimated to be less than 0.001 rem.

The primary mission of the NTS is the underground testing of nuclear weapons. The activities and conditions under which radionuclide releases could occur are described in the the Final Environmental Impact Statement, Nevada Test Site, Nye County, Nevada (ERDA, 1977). Releases from these nuclear activities are governed by DOE Order 5480.1, which include the DOE requirements for radiation protection (DOE, 1980a). Underground repository activities may be temporarily suspended during a nuclear test. This action would be taken as a special precaution for certain underground tests depending on their location in relation to the repository. Because the DOE exercises control over the schedule of activities at the NTS, compatible arrangements for nuclear testing and repository construction-operation activities can be made. The current policy of the DOE Nevada Operations Office requires the removal of workers from underground mines within about 80 kilometers (50 miles) of an underground test of approximately 80 kilotons or larger (Vortman, 1980). The removal of workers from the underground facility would be a standard industrial practice to guarantee the safety of workers. Other preparations might include the purging of contaminated hot-cell atmospheres or the securing of waste disposal containers and spent fuel assemblies. Plans for the evacuation of facilities that are judged to be particularly hazardous could also be developed.

The Environmental Protection Agency conducts an Offsite Radiological Safety Program, which includes monitoring of the NTS. This program uses several monitoring networks for measuring radioactivity and radiation levels in the site environs. Radiation from the underground testing at the NTS is not expected to endanger repository-worker safety or adversely affect repository activities. On very infrequent occasions, underground nuclear explosions at the NTS release small amounts of radioactivity to the atmosphere. Data for airborne radionuclides from the NTS detected off the site from 1974 through 1983 are provided in Table 6-7. As shown in Table 6-7, no detectable levels of radioactivity from the underground tests were observed

Table 6-7. Airborne radionuclides from the Nevada Test Site detected off the site, 1974 through 1983

Year	Station Detecting Radionuclides[a]	Radionuclides detected	Highest calculated individual whole-body dose[b] (microrem)	Population dose[c] (man-rem)
1974[d]	Beatty,* Diablo, Indian Springs	Xe-133	.	0.003
1975[e]	Beatty,* Diablo, Hiko, Indian Springs, Las Vegas	Xe-133, Kr-85, H-3	2.1	0.00065
1976[f]	Death Valley Junction*	H-3	1.3	0.00078
1977[g]	Beatty,* Diablo, Hiko, Las Vegas, Tonopah	Xe-133	2.5	0.0013
1978[h]	Diablo, Indian Springs*	Xe-133, H-3	6.2	0.0087
1979[i]	None	None	0	0
1980[j]	Lathrop Wells* (Amargosa Valley)	Xe-133, Xe-135	11	0.00072
1981[k]	None	None	0	0
1982[l]	None	None	0	0
1983[m]	None	None	0	0

[a] All communities in Nevada. Those communities marked with an asterisk (*) are within 80 km (50 miles) of the proposed repository surface facilities complex.

[b] Dose calculated from the largest amount detected (not necessarily within the 80-km (50-mile) radius. For perspective, the largest dose listed (11.0 microrem or 11.0×10^{-6} rem) is only 0.005 percent of the average annual dose an individual in this area receives from naturally occurring internal and external radiation and 0.001 percent of the Nuclear Regulatory Commission radiation protection standard of 0.5 rem per year (10 CFR Part 20, 1984).

[c] Population dose calculated using the radionuclide detected and the population within the 80-km (50-mile) circle. The population dose, sometimes referred to as collective dose, is simply a summation of the doses received by individuals in an exposed population. For example, if each member of a population of 100 individuals received a dose of 0.1 rem, the population dose would be 10 man-rem. These population doses are extremely small compared with the annual population dose of 400 man-rem from naturally occurring radiation received by the 4,600 people living within the area analyzed (Patzer et al., 1984).

[d] Data from EPA (1975).
[e] Data from EPA (1976).
[f] Data from EPA (1977).
[g] Data from Grossman (1978).
[h] Data from Grossman (1979).
[i] Data from Potter et al. (1980).
[j] Data from Smith et al. (1981).
[k] Data from Black et al. (1982).
[l] Data from Black et al. (1983).
[m] Data from Patzer et al. (1984).

outside the NTS boundaries during four of the past five 1-year monitoring periods. Section 2.4.7.2 presents discussions of dose assessments for a hypothetical individual at the NTS boundary, and shows that assuming this individual receives a 1-year intake of air and water with radionuclide concentrations measured on the site, the dose represents less than 0.5 percent increase over natural background for total body and lungs, and less than 1.5 percent increase for bone. Regulations for the containment of radiation from underground nuclear tests are very stringent (ERDA, 1977).

If a repository is built at Yucca Mountain, it must be built to withstand the ground motion from natural earthquakes and from underground nuclear explosions. It should be recognized that explosion-induced aftershocks are generally confined to within 14 kilometers (8.7 miles) of the site of explosion (Hamilton et al., 1971). An acceleration-prediction equation has been developed on the basis of experimental data from 21 tests at Pahute Mesa (Vortman, 1980). The equation predicts that the mean peak vector ground acceleration at Yucca Mountain from underground nuclear explosions at the maximum allowable yield (based on offsite damage restrictions) would be 0.061g, resulting from a 700-kiloton test at the Buckboard area. The mean ground acceleration plus 3 standard deviations (99 percent of all probable values) is 0.32g, based on the preceding value of predicted mean peak vector ground acceleration. This is a more conservative approach than that used for nuclear-reactor siting, which requires only mean ground acceleration plus 1 standard deviation (68 percent of all probable values) (Vortman, 1980).

A worst-case repository accident scenario resulting from an underground nuclear explosion considered by Jackson et al. (1984) estimates the consequences of a surface acceleration of 0.32g at the repository site. The scenario included an assumption that the acceleration was accompanied by several unlikely failures in the repository surface facilties. It assumed that, through human error, the hot-cell atmosphere had not been purged, an electrical failure occurred, and pressure regulation in the hot cell was lost. The hot-cell seals were assumed to fail, and scale from fuel rods and fission gases were assumed to be released into the waste-preparation facility. The contaminated air was assumed to eventually be vented through a roughing filter and two banks of high-efficiency particulate air filters to the stack. The probability of this event was calculated to be less than 1.0×10^{-3} per year. Calculations for the maximum individual 50-year total-body dose commitment for this scenario give 2.4×10^{-4} rem at a postulated exclusion boundary about 4 kilometers (2.5 miles) from the facility. For comparison, the individual whole-body dose limit for normal operations in unrestricted areas is 0.5 rem per year (10 CFR Part 20, 1984). The general population, conservatively estimated for this evaluation at 19,908 within 80 kilometers (50 miles) of the potential repository site, would receive 3.1×10^{-3} man-rem. These upper limits to doses caused by the surface acceleration and multiple failures are much smaller than doses from natural background. Natural background sources contribute an individual total-body equivalent dose of 0.09 rem per year and an annual external whole-body population dose commitment of about 1,790 man-rem to the same 19,908 people (Jackson et al., 1984). The population within 80 kilometers (50 miles) of the repository was conservatively estimated by identifying the counties within an 80-kilometer (50-mile) radius of the proposed repository, and dividing the 1980 county population by the county area to obtain the

population density (see Section 6.2.1.2). If population centers (i.e., cities or unincorporated places) are accounted for, the population within 80 kilometers (50 miles) of the proposed repository is estimated to be 11,674 (Morales, 1985).

Calculations for the worker dose commitments from this same accident (Jackson et al., 1984) indicate that the total-body 50-year dose commitment received by an individual worker would be 0.37 rem. Whole-body occupational dose limits for individual workers for routine operations in 10 CFR Part 20 (1984) are 5 rem per year or 3 rem per quarter. The whole-body equivalent dose received by an individual worker from background sources is about 0.09 rem per year.

Conclusion

Present or projected activities on the NTS and the NAFR should have no significant adverse impacts on a repository at Yucca Mountain. There is a very remote possibility of a radioactive release caused by the crash of a military aircraft from Nellis Air Force Range. The Nevada Test Site could, however, adversely affect the repository in two minor ways. The removal of workers from the underground portion of the repository during certain nuclear tests will cause a minor disruption in repository activities. There is also a very unlikely possibility that an underground nuclear test at the NTS could release sufficient radioactivity to the atmosphere to affect repository activities. Therefore, the evidence indicates that this potentially adverse condition is present at Yucca Mountain.

(2) Presence of other nuclear installations and operations, subject to the requirements of 40 CFR Part 190 or 40 CFR 191, Subpart A, with actual or projected releases near the maximum value permissible under those standards.

Evaluation

The provisions of 40 CFR Part 190 (1982) apply to radiation doses received by members of the public and to radioactive materials introduced into the general environment as a result of operations which are a part of the nuclear fuel cycle. The nuclear fuel cycle operations covered by 40 CFR 190 (1982) are those associated with the nuclear generation of electrical power for public use but does not include operations at a waste disposal site. Subpart A of 40 CFR Part 191 (1985) applies to radiation doses received by members of the public as a result of the management (except for transportation) and storage of spent nuclear fuel and high-level radioactive waste, to the extent that these operations are not subject to the provisions of 40 CFR Part 190 (1982).

Neither regulation applies to the nuclear-weapons testing at the NTS or to the low-level radioactive waste disposal site near Beatty, 31 kilometers (19 miles) west of Yucca Mountain.

Conclusion

There are no nuclear installations or operations in the vicinity of the Yucca Mountain site with potential releases governed by 40 CFR Part 190

(1982) or 40 CFR 191, Subpart A (1985). Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

6.2.1.5.5 Disqualifying condition

A site shall be disqualified if atomic energy defense activities in proximity to the site are expected to conflict irreconcilably with repository siting, construction, operation, closure, or decommissioning.

Evaluation

The Yucca Mountain site is over 40 kilometers (25 miles) from the nearest area presently used for underground nuclear detonations. Potential areas for future underground nuclear testing that are closer to the Yucca Mountain site are shown in Figure 6-1, and none are closer than approximately 23 kilometers (14 miles). The Yucca Mountain site is not in an area where surface activities are normally suspended and individuals removed as a routine precautionary measure during underground testing activities elsewhere at the Nevada Test Site (NTS). However, the current policy of the U.S. Department of Energy Nevada Operations Office requires the removal of workers from underground mines within about 80 kilometers (50 miles) of an underground test of approximately 80 kilotons or larger (Vortman, 1980) and for certain other tests if there is larger than normal uncertainty in the effects of the detonation. Such a policy would have an effect during the siting, construction, operation, closure, and decommissioning of the repository.

Extensive studies of ground motion induced by underground nuclear explosions have been used to investigate the potential conflict between atomic energy defense activities and a repository at Yucca Mountain. Fourteen mines within 50 kilometers (31 miles) of the NTS boundaries have been under surveillance by the U.S. Bureau of Mines to determine the nature and the extent of damage from ground motion induced by underground nuclear tests. No damage to offsite mines had been reported through 1977 (ERDA, 1977), and more recent information is not available.

A nuclear test at Rainier Mesa in February 1984 resulted in an unexpected subsidence crater on the surface, causing injuries and one fatality. The nuclear device had been exploded at about 360 meters (1,184 feet) below the surface (DOE/NVO, 1984), and the persons injured were involved in postshot activities only 26 meters (85 feet) from the point on the surface that was directly above the explosion. Surface cratering occurs above some underground nuclear tests. All known effects, such as fractures, have been very close to the site of the explosion. Ninety-five percent of the after-shocks at Pahute Mesa have been found to be within 14 kilometers (8.7 miles) of the explosion site (ERDA, 1977). The Yucca Mountain site is sufficiently distant from present or potential underground test locations that collapse or formation of fractures is highly unlikely.

In an analysis of the compatibility of a repository at the Yucca Mountain site and the weapons-testing program with respect to ground motion, Vortman (1982) summarized the following significant differences between ground motion from weapons tests and natural earthquakes: (1) the timing of weapons tests is known and controlled; (2) the seismic-source location for a

weapons test is known; (3) a conservative upper limit on the expected explosion energy is available; and (4) an experienced test organization controls the safety aspects of weapons tests. Standard operating practices should be able to ensure personnel safety and protect surface and underground facilities.

Using an empirical relationship developed on the basis of ground motion studies from past weapons tests, Vortman (1982) investigated potential conflicts with respect to induced ground motion between the underground weapons-testing program and a geologic repository at Yucca Mountain. His results show that if a repository was designed for a 0.75g ground acceleration, then it could be built as close as 6.3 kilometers (3.9 miles) to a 700-kiloton nuclear detonation. The closest location at the NTS with a potential for a 700-kiloton detonation is the Buckboard area, and it is 23 kilometers (14 miles) from the Yucca Mountain site, more than 3 times farther than the 6.3 kilometers (3.9 miles) calculated by Vortman (1982). Ground motion from aftershocks that follow large nuclear tests has also been considered and should not cause additional problems; as noted above, 95 percent of the stimulated earthquake activity is confined to within 14 kilometers (8.7 miles) of the detonation point. Aftershocks fall off to the background level within a period of several weeks, and the strongest aftershock is usually at least 2 magnitude units (on a logarithmic scale) less than the explosion (ERDA, 1977).

A repository at the Yucca Mountain site can be designed and constructed using available technology to withstand the maximum credible predicted ground motion, whether natural or induced (see discussion in Section 6.3.3.4.5). Using the empirical equation from Vortman (1980), the predicted mean peak vector ground acceleration at Yucca Mountain from underground nuclear explosions at the maximum allowable yields, based on offsite damage restrictions, is calculated to be 0.061g. Using a very conservative design criterion of three standard deviations, or 99 percent of all probable values, the mean peak vector ground acceleration for Yucca Mountain is calculated to be 0.32g. The yields used for this calculation are well above the 150-kiloton limit currently allowed by the Threshold Test Ban Treaty. The suspension of certain activities at the repository site can be planned as a standard operating procedure. These suspensions will be infrequent and of short duration; they will not have significant adverse effects on any phase of repository activities.

No detectable levels of radioactivity from the underground testing program were observed outside the NTS boundaries during four of the past five 1-year reporting periods for which data have been compiled (see Table 6-7). Current radiation-containment and safety measures are more stringent than in the past, and the possibility of substantial releases of radioactivity to the atmosphere in the future is considered very small (ERDA, 1977). Radioactivity attributable to the resuspension of dust particles in the air from contaminated areas at the NTS has never been detected off the site (ERDA, 1977).

Conclusion

All potential impacts from atomic energy defense activities occurring elsewhere at the NTS can be accommodated by careful facility design and

construction and through the compatible scheduling of repository operations and nuclear weapons testing activities. Consequently, atomic energy defense activities in proximity to the site are not expected to conflict irreconcilably with repository siting, construction, operation, closure, and decommissioning. Therefore, the evidence does not support a finding that the Yucca Mountain site is disqualified (level 1).

6.2.1.5.6 Evaluation and conclusion for the qualifying condition on the offsite installations and operations guideline

Evaluation

A repository at Yucca Mountain will be designed and constructed to withstand the ground motion predicted from nuclear-weapons testing at the Nevada Test Site (NTS) and from natural earthquakes. The design of earthquake-resistant structures will incorporate engineering experience and consider the maximum potential ground motion. There were no radionuclide releases from the NTS detected off the site during four of the past five 1-year monitoring periods. This information, combined with estimates of radionuclide releases from worst-case accident scenarios, provides confidence that radionuclide releases to an unrestricted area will not exceed allowable limits. Two or three nuclear tests per year may require temporary suspension of repository activities, usually not exceeding 12 hours. The portion of Nellis Air Force Range near Yucca Mountain is used only for military-aircraft overflights. These over-flights will increase noise in the area, and there is an extremely remote chance that an airplane might crash in the vicinity of the site; the probability of such a crash has been estimated at less than 2.0×10^{-10} per year (Jackson et al., 1984).

Releases during normal repository operation are discussed in Section 6.4.1. The estimated annual dose equivalent due to normal releases would be approximately 2 percent of background. The estimated worst-case accidental radionuclide release from the repository results from an aircraft impact accident, which causes a maximum individual total-body dose of 5.5×10^{-2} rem or a 50-year dose commitment of 6.8×10^{-2} rem (Jackson et al., 1984). This accident has a very low risk (less than 2.2×10^{-8} man-rem per year) because the probability of occurrence of this accident is extremely small, less than 2.0×10^{-10} per year. If the dose from this very unlikely scenario is considered together with the maximum dose calculated for releases detected off the site from 1974 to 1983 (11 microrem in 1980), the maximum possible total-body dose would increase by only 0.02 percent, not enough to cause regulatory limits to be exceeded.

Conclusion

Nearby industrial and military installations and operations will not significantly affect a potential repository at Yucca Mountain during siting, construction, operation, closure, or decommissioning. Possible short-term interruption of activities at a repository due to weapons tests is not considered a significant effect. Any potential emissions during construction, operation, closure, and decommissioning in combination with those that might occur from activities at the NTS will not lead to radionuclide releases to an unrestricted area greater than allowable under present regulations. This is true for both normal repository operation and for worst-case accident

scenarios. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for offsite installations and operations (level 3).

6.2.1.6 Environmental quality (10 CFR 960.5-2-5)

6.2.1.6.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall be located such that (1) the quality of the environment in the affected area during this and future generations will be adequately protected during repository siting, construction, operation, closure, and decommissioning, and projected environmental impacts in the affected area can be mitigated to an acceptable degree, taking into account programmatic, technical, social, economic, and environmental factors; and (2) the requirements specified in Section 960.5-1(a)(2), can be met.

The preclosure environmental-quality technical guideline is concerned with ensuring that the quality of the natural and human environment will be protected throughout all stages of the geologic-repository program and that the projected impacts can be mitigated to an acceptable degree.

The guideline contains two favorable conditions, six potentially adverse conditions, three disqualifying conditions, and one qualifying condition. The evaluations presented below are summarized in Table 6-8.

6.2.1.6.2 Data relevant to the evaluation

The following information was used to evaluate the Yucca Mountain site against the guideline on environmental quality: (1) published reports describing the archaeology, biology, hydrology, meteorology, and radiology of the Yucca Mountain area (see Chapter 3); (2) a preliminary investigation of the regulatory requirements that could apply to a repository at Yucca Mountain (see favorable condition 1); (3) a variety of land-status maps published by the State of Nevada and by the Bureau of Land Management (see potentially adverse condition 2); and (4) the results of analyses in chapters 4 and 5 that describe the expected near- and long-term environmental consequences of repository siting, construction, operation, closure, and decommissioning at Yucca Mountain.

Table 6-9 presents a preliminary list of the Federal regulatory requirements that may apply to repository siting, construction, operation, closure, and decommissioning at Yucca Mountain.

Table 6-10 lists State environmental regulatory requirements. There are no applicable local environmental requirements. The U.S. Department of Energy (DOE) intends to comply with all State and local environmental requirements not inconsistent with its responsibilities under the Nuclear

Table 6-8. Summary of analyses for Section 6.2.1.6; environmental quality (10 CFR 960.5-2-5)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITIONS	
(1) Projected ability to meet, within time constraints, all Federal, State, and local procedural and substantive environmental requirements applicable to the site and the activities proposed to take place thereon.	The evidence indicates that this favorable condition is present at Yucca Mountain: no problems are expected in siting, constructing, operating, closing, and decommissioning the repository in compliance with applicable environmental requirements.
(2) Potential significant adverse environmental impacts to present and future generations can be mitigated to an insignificant level through the application of reasonable measures, taking into account technical, social, economic, and environmental factors.	The evidence indicates that this favorable condition is present at Yucca Mountain: potential impacts are not expected to be significant; mitigation measures can be taken to further reduce those adverse impacts that may result from siting, closing, and decommissioning a repository at Yucca Mountain.
POTENTIALLY ADVERSE CONDITIONS	
(1) Projected major conflict with applicable Federal, State, or local environmental requirements.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: no major conflicts with existing requirements have been identified.
(2) Projected significant adverse environmental impacts that cannot be avoided or mitigated.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: potential impacts are not expected to be significant; mitigation measures can be taken to further reduce those adverse impacts that may result from siting, constructing, operating, closing, and decommissioning a repository at Yucca Mountain.

Table 6-8. Summary of analyses for Section 6.2.1.6; environmental quality (10 CFR 960.5-2-5) (continued)

Condition	Department of Energy (DOE) finding
(3) Proximity to, or projected significant adverse environmental impacts of the repository or its support facilities on a component of the National Park System, the National Wildlife Refuge System, the National Wild and Scenic Rivers System, the National Wilderness Preservation System, or National Forest Land.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: the proposed rail line within a few miles of the Desert National Wildlife Range is not expected to have an adverse effect on animals or people on the range; there are no other federally protected lands that could be significantly affected.
(4) Proximity to, and projected significant adverse environmental impacts of the repository or its support facilities on a significant State or regional protected resource area, such as a State park, a wildlife area, or a historical area.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: a proposed rail line may pass about 2 kilometers (1 mile) north of a State park, but noise is not expected to exceed EPA limits; no other resource area is affected.
(5) Proximity to, and projected significant adverse environmental impacts of the repository and its support facilities on a significant Native American resource, such as a major Indian religious site, or other sites of unique cultural interest.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: few archaeological or historical sites may be affected during construction, but sites that could be disturbed will be excavated, and artifacts will be collected and (or) catalogued.

Table 6-8. Summary of analyses for Section 6.2.1.6; environmental quality (10 CFR 960.5-2-5) (continued)

Condition	Department of Energy (DOE) finding
(6) Presence of critical habitats for threatened or endangered species that may be compromised by the repository or its support facilities.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain because no listed threatened or endangered species occur in the study area. The repository and support facilities are not expected to have significant adverse impact on the two species under review as threatened or endangered or on the State-protected species. The nearest endangered species are pupfish that occur in Ash Meadows 40 kilometers (25 miles) south of the site; their habitat is protected by land-use restrictions, and is located in a different ground-water basin.
QUALIFYING CONDITION	
The site shall be located such that (1) the quality of the environment in the affected area during this and future generations will be adequately protected during repository siting, construction, operation, closure, and decommissioning, and projected environmental impacts in the affected area can be mitigated to an acceptable degree, taking into account programmatic, technical, social, economic, and environmental factors; and (2) the requirements specified in Section 960.5-1(a)(2) can be met.	Existing information does not support a finding that the site is not likely to meet the qualifying condition (level 3): no projected significant impacts have been identified, and there is no reason to expect that applicable environmental requirements cannot be met by designs and procedures during siting, constructing, operating, closing, and decommissioning of a repository at Yucca Mountain. The public and the environment are expected to be adequately protected from the hazards posed by the disposal of radioactive waste.

Table 6-9.   Preliminary summary of Federal environmental regulatory
            requirements that may apply to a repository at Yucca
            Mountain (See footnotes at the end of the table)

Authority	Project Feature	Substantive Requirements

REQUIREMENTS RELATED TO LAND

Authority	Project Feature	Substantive Requirements
National Environmental Policy Act of 1969 (NEPA). Compliance with regulations.	Major Federal actions significantly affecting the quality of the human environment.	This Act requires Federal agencies to assess the environmental impacts of major Federal actions to prevent or eliminate damage to the environment.
Federal Land Policy and Management Act, and summary report on 43 USC[a] 1701-1782. Right-of-Way Grant (BLM[b] or USFS[c]).	Occupation, use, or traversing of land for roads, railroads, power, construction camps, storage yards, etc., will affect BLM land.	A description of the land environmental effects; BLM evaluates effects and sends written authorization.
Fish & Wildlife Coordination Act, 16 USC 661 et seq., Section 4(f); Department of Transportation Act of 1966, 80 Stat. 931, P.L.89-870; National Wildlife Refuge System Administration Act, P.L. 89-669, (USFWS[d], DOI[e]). Right-of-Way Consultation.	Occupation, use, or traversing of land for power and railroads over national wildlife refuges. Effects to the Desert National Wildlife Range, are not expected. The Secretary of Transportation must approve a transportation project if publicly owned land containing a public park, recreation area, or wildlife area are affected.	A description of the species, the habitat, and how the proposed action may affect the species; USFWS or DOT[f] evaluates information; needed action, and instructs applicant.
Federal Land Policy and Management Act, 43 USC 155-158, (BLM, USFS). Withdrawal Land Order.	Obtaining jurisdiction over, use of, or occupation of public land for facilities and structures will affect BLM land.	An environmental assessment may be required.

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Table 6-9. Preliminary summary of Federal environmental regulatory
requirements that may apply to a repository at Yucca
Mountain (See footnotes at the end of the table) (continued)

Authority	Project Feature	Substantive Requirements
Federal Land Policy and Management Act, sections 103(f), 302(b), 501(a)(7), 504(a), and 507(a) (BLM, USFS). Temporary Use Permit.	Occupation, use, or traversing of public land to study, monitor, or perform other investigations will affect BLM land.	A description of the land and a summary report on environmental effects; BLM returns an approved permit application form.
Organic Act of the National Park Service, 16 USC Section 1; National Park System Mining Regulation Act, 16 USC Section 1901-1912 (36 CFR[g] Part 9).	Occupation, use, or traversing of National Park land. To preserve National Parks and to leave them unimpaired for future generations with special emphasis on halting or regulating mining so as to prevent or minimize damage to the environmental resources.	A description of the land and a summary report on the environmental impact; this Act is not applicable because the restricted area or repository support facilities will not lie within a National Park.
Department of Transportation Acts, 49 USC Section 303, 23 USC Section 138.	Occupation, use, or traversing of public land for transportation corridors. To preserve the natural beauty of the countryside, public parks, recreation lands, wildlife and waterfowl refuges, and historic sites.	A description of the land and a summary report on the environmental impacts; although the Acts do not impose any requirements directly on the DOE[h], the DOE will consult with the Department of Transportation to determine the applicability.
Coastal Barriers Resources Act, 16 USC 3501-3510.	Prohibits new Federal expenditures for construction of projects within the Coastal Barrier Resources System (CBRS), undeveloped coastal land along the Atlantic and Gulf Coasts, and adjacent wetlands and inlets.	DOE determines if candidate site or related activities are within CBRS; if so, site or activities must be abandoned. DOE confirms with U.S. Fish and Wildlife Service that no project activities are located in a coastal barrier.

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Table 6-9. Preliminary summary of Federal environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at the end of the table) (continued)

Authority	Project Feature	Substantive Requirements

REQUIREMENTS RELATED TO LAND (continued)

Authority	Project Feature	Substantive Requirements
Coastal Zone Management Act of 1972, 16 USC 1451-1464 (15 CFR 930).	Coastal Zone Management Act ensures that any Federal project in the coastal zone, is consistent with approved state management programs.	DOE determines if project activities are in, or could affect, the coastal zone of a state. If DOE determines that a coastal zone is affected, or that ocean dumping is proposed, additional requirements apply.
Marine Protection, Research, and Sanctuaries Act, 33 USC 1401-1444 (10 CFR 220-228).	Marine Protection, Research, and Sanctuaries Act regulates the dumping of all types of materials into ocean waters.	If DOE determines that ocean dumping is proposed, additional requirements apply.
Wild and Scenic Rivers Act, 16 USC 1271-1287.	Act prohibits construction on or directly affecting any river that is designated a component of the National Wild and Scenic River (NWSR) system, or on any river designated for addition to the system, that would adversely affect the values of NWSR systems.	DOE determines if any rivers in the vicinity of the candidate repository site are designated as a component of the NWSR system, or a potential addition to the system. If DOE finds an NWSR in site vicinity, it must prepare an impact evaluation. If impacts are direct and adverse, DOE must advise the Secretary of the Department of Interior and Congress.
Wilderness Act, 16 USC 1131-1136. (Federal Land Policy and Wilderness Management Act, 43 USC 1982).	Act establishes a National Wilderness Preservation System for public recreational, scenic, scientific, educational, conservation, and historical use.	Roads, structures, installations, etc., are prohibited in designated Areas or Wilderness Study Areas (WSAs).

Authority	Project Feature	Substantive Requirements

REQQUIREMENTS RELATED TO LAND (cont nued)

Authority	Project Feature	Substantive Requirements
Taylor Grazing Act 43 USC 315-316 (43 CFR 4100).	Act creates, protects, and regulates Federal grazing districts to provide for the orderly use and development of rangeland.	If repository site or access is located on a DOI Bureau of Land Management (BLM) designated grazing district, DOE must apply for a right-of-way, or withdrawal of grazing district land from BLM.
National Forest Organic Legislation, 16 USC 475; Multiple-Use-Sustained-Yield Act, 16 USC 528-531; Forest and Rangeland Renewable Resources Planning and Research Acts, Management Act, and Renewable Resource Extension Act, 16 USC 1600-1676 (36 CFR Part 261).	Acts protect and improve National Forests which are established for outdoor recreation, range, timber, watershed, and fish and wildlife purposes.	DOE must obtain Congressional approval for withdrawal of National Forest land for DOE use as a repository site. Access roads on National Forest land must be built in accordance with requirements defined by the DOA[1]. Permanent roads must be approved as part of National Forest Transportation System.
Farmland Protection Policy Act, 7 USC 4201-4209 (7 CFR 658).	Act seeks to minimize the extent to which Federal programs contribute to the unnecessary and irreversible conversion of farmland to nonagriculture uses.	DOE must complete Soil Conservation Service (SCS) Form AD 1006, and submit to SCS. If SCS determines that prime farmland exists on site, DOE must complete a site assessment. DOE must also consider alternative/mitigating measures to protect the prime farmland, and assure to extent practicable, project compatibility with State and local programs and policies.

Table 6-9. Preliminary summary of Federal environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at the end of the table) (continued)

Authority	Project Feature	Substantive Requirements

REQUIREMENTS RELATED TO LAND (cont.nued)

Authority	Project Feature	Substantive Requirements
Floodplains/Wetlands Executive Orders, E.O. 11988 and 11990 (10 CFR 1022).	Executive Orders require Federal agencies to implement regulations that will protect wetlands, and minimize adverse effects from development in floodplains.	If wetlands or floodplains occur at the site or support facilities, DOE must publish notice in Federal Register, notify Federal, State, and local agencies of proposed action, prepare an assessment of proposed action, and publish a statement of findings. Construction in a flood plain must be in accordance with Federal Insurance Administration regulations.

REQUIREMENTS RELATED TO AIR OR NOISE

Authority	Project Feature	Substantive Requirements
Clean Air Act, 42 USC 7401, et seq. (Regional EPA Office). Preconstruction Permit under Prevention of Significant Deterioration (PSD) or nonattainment regulations; EPA[J] review only for states with delegated authority.	Any major stationary source including concrete or asphalt batch plants, fossil-fuel-fired equipment diesel generator, storage of volatile organic compounds, etc.	An emission inventory, meteorology data, dispersion modeling, and an evaluation of NAAQS[K] and PSD standards; EPA returns signed application forms.
Clean Air Act, 42 USC 7410(a)(2)(D), 110(a)(4) (State Air Quality Office). New Source Review (NSR) provisions of the Clean Air Act authorize States to regulate sources not subject to PSD through permit programs.	Small sources and sources not subject to PSD or nonattainment review, but subject to new source operating standards and emission limitations.	A list of emissions and emission sources; EPA uses NSR to ensure compliance with New Source Review emission standards; EPA issues NSR approval; activity must be included in approved State Implementation Plan (SIP).

Table 6-9. Preliminary summary of Federal environmental regulatory
requirements that may apply to a repository at Yucca
Mountain (See footnotes at the end of the table) (continued)

Authority	Project Feature	Substantive Requirements

REQUIREMENTS RELATED TO AIR OR NOISE (continued)

Authority	Project Feature	Substantive Requirements
Noise Control Act of 1972, 42 USC 4901-4918.	Federal agencies are to carry out their programs in a manner that promotes an environment free of noise that could jeopardize health or welfare.	DOE is required to comply with Federal, State, interstate, and local requirements for the control and abatement of environmental noise.

REQUIREMENTS RELATED TO WATER

Authority	Project Feature	Substantive Requirements
Federal Land Policy and Management Act, 43 USC 1767 (BLM). Right-of-Way Grants.	Well sites on BLM land.	Well specifications, location, use, and brief description of environmental effects; BLM returns a signed right-of-way form.
Clean Water Act 33 USC 1251, et seq. (Regional EPA Office). National Pollutant Discharge Elimination System Permit.	Discharge of pollutants into project surface lagoons that could subsequently lead to contamination of surface or ground waters.	Discharge quantity, water quality data, and information on receiving waters; EPA returns a signed application form.
Clean Water Act, Sec. 404, 33 USC 1344; Executive Orders 11988 and 11990 (District U.S. Coast Guard). 404 Permit/ Consultation.	Discharge of dredged material for purposes of building impoundments, causeways, roadfills, dams, or dikes in navigable waters, including wetlands; depends on the official classification of Fortymile Wash.	Description of activity and environmental impact report; ACOE[1] returns a signed application form.
Clean Water Act, Sec. 311(j)(1)(c); 40 CFR 112 (Regional EPA Office). Approval of Spill Prevention Control and Counter-measure (SPCC) Plan.	Storage and transport of hydrocarbons near navigable waters; spill prevention depending on the classification of Fortymile Wash.	Location and specifications of tanks and berms to confine spills; EPA approves the SPCC Plan in writing.

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Table 6-9. Preliminary summary of Federal environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at the end of the table) (continued)

Authority	Project Feature	Substantive Requirements

REQUIREMENTS RELATED TO WATER (continued)

Authority	Project Feature	Substantive Requirements
Rivers and Harbors Act, 33 USC 401-413 (33 CFR 323).	Act prevents any alteration or modification of the course, location, conditions, or capacity of any channel of any navigable water of the U.S. without a permit.	DOE must obtain a permit from ACOE if fill material is put into navigable water.
General Bridge Act of 1946, 33 USC 401 (33 CFR 114-115).	Act requires permit or amendment from U.S. Coast Guard for construction or modification of bridges over any navigable waterways.	DOE must apply for permit if any bridge over navigable waterways will be built or modified as a result of repository activities at the site.
Safe Drinking Water Act, 42 USC 300f-300g-10 (40 CFR 122 and 146).	The purpose of the Act is to prevent pollution of underground sources of drinking water, to protect sole source aquifers and to require compliance with Federal, State, and local public drinking water regulations.	DOE must obtain an Underground Injection Control Permit or use a licensed underground injection well facility, if underground injection is chosen as method of disposal for brine.

REQUIREMENTS RELATED TO SOLID AND HAZARDOUS WASTE

Authority	Project Feature	Substantive Requirements
Hazardous Materials Transportation Act, 49 USC 1801, et seq. Registration	Packing, labeling, handling, documenting, and transporting hazardous materials on public roads, railways, etc. across state lines; hazardous materials include flammable liquids, combustible liquids, explosives, etc.	Documentation of materials to be transported; DOT returns a signed registration form.

Authority	Project Feature	Substantive Requirements

REQUIREMENTS RELATED TO SOLID AND HAZARDOUS WASTE (continued)

Authority	Project Feature	Substantive Requirements
Resource Conservation and Recovery Act, USC 6901, et seq. (Regional EPA Office). Hazardous Waste Identification Number.	Generation and transport of hazardous wastes in quantities exceeding 1,000 kg/month or acute hazardous wastes exceeding 1 kg/month.	Quantity and type of waste and a description of disposal site before, during, and after disposal; EPA returns a signed application form.
Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), 42 USC Sections 9601-9657.	Generation and transport of hazardous wastes. The Act imposes notification requirements and liability for unpermitted releases of hazardous substances, and to establish a fund for remedial use in case of release of hazardous substances.	Notification and clean up of accidental spills in accordance with CERCLA requirements.
Resource Conservation and Recovery Act, USC 6901, et seq. (Regional EPA Office). Hazardous Waste TSD Permit (necessary for any state without an EPA-approved hazardous-waste-management plan).	Construction and operation of any facility used for the treatment, storage, and disposal (TSD) of hazardous wastes including possibly the rock-storage pile.	Quantity and type of waste and a description of disposal site before, during, and after disposal; EPA returns a signed application form.

REQUIREMENTS RELATED TO CULTURAL RESOURCES AND NATIVE AMERICANS

Authority	Project Feature	Substantive Requirements
American Indian Religious Freedom Act, 42 USC 1996 et seq. Consultation with Native American religious leaders, BIA[m], DOI.	Impact of construction on American religious practices and sites.	Location of project activities and sites; DOI returns written authorization to proceed with project.

Table 6-9.   Preliminary summary of Federal environmental regulatory
            requirements that may apply to a repository at Yucca
            Mountain (See footnotes at the end of the table) (continued)

Authority	Project Feature	Substantive Requirements

REQUIREMENTS RELATED TO CULTURAL RESOURCES AND NATIVE AMERICANS (continued)

Authority	Project Feature	Substantive Requirements
National Historic Pre-servation Act, 16 USC 470 et seq., Executive Order 11593; 35 CFR 800. (Advisory Council on National Historic Pre-servation; State Historic Preservation Office). Determination of No Adverse Effect; Pro-grammatic Memorandum of Agreement; Avoidance and Mitigation for land withdrawal where exca-vations or removal of archaeological resour-ces are anticipated.	Impact of construction on cultural resources.	As above, DOI action required.
Archaeological Resources Protection Act of 1979, 16 USC 470 aa et seq. (BLM, DOI, DOA). Permit to excavate, remove, or alter archaeological resources.	Impact of construction on cultural resources.	As above, and a detailed excavation preservation plan; DOI must approve the plan.
American Antiquities Act, 16 USC 433.	Act protects historic and prehistoric ruins, monuments, and objects of antiquity located on lands owned or controlled by the Federal Government.	If historic or prehis-toric ruins or objects of antiquity are found, DOE must determine if project will adversely affect sources. Secretary of the DOI will have to grant permission to pro-ceed before activities can be undertaken that may result in appropri-ation, excavation, injury, or destruction to any historic ruin or antiquity.

Authority	Project Feature	Substantive Requirements

REQUIREMENTS RELATED TO CULTURAL RESOURCES AND NATIVE AMERICANS (continued)

Authority	Project Feature	Substantive Requirements
Reservoir Salvage Act of 1960, 16 USC Section 469-469c (at 469 a-1) (DOI). Survey for recovery and preservation of archaeological resources discovered in the course of siting a Federal project.	Impacts of construction on cultural resources.	As above, DOI action required.
National Trails System Act, 16 USC, Section 1241 et seq. (NPS[n], DOI). Cooperative Agreement for construction and operation on historic trails.	Impacts of construction on historic trails.	As above, DOI action required.
Historic Sites, Buildings and Antiquities Act, 16 USC 461-469; Preservation of Historical Archaeological Data Threatened by Dam Construction or Alteration; Historic Preservation Act of 1966 as Amended, 16 USC 470-470w-6 (36 CFR Part 800); (E.O. 11593).	Act protects properties of historical architectural significance at National, State, and local levels from Federal actions affecting properties included in or eligible for inclusion in the National Register of Historic Places.	DOE must request information from State Historic Preservation Officer (SHPO) and study existing literature to determine whether potential structures or objects that are listed in the National Register or are eligible for inclusion in the National Register will be affected. If potential repository site contains historic resource that is eligible for inclusion in the National Register, DOE must determine the effect that repository construction may have on the resource.

Table 6-9. Preliminary summary of Federal environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at the end of the table) (continued)

Authority	Project Feature	Substantive Requirements

REQUIREMENTS RELATED TO CULTURAL RESOURCES AND NATIVE AMERICANS (continued)

| | | If effect would be adverse, DOE must prepare a plan of mitigation and consult with the Advisory Council on Historic Preservation. |

REQUIREMENTS RELATED TO CONSTRUCTION MATERIALS

| Materials Act 1947, 30 USC 601-604 (43 CFR 3600 et seq.) (BLM, DOI). Free Use Permit. | Acquisition (from BLM lands) and use of common varieties of sand, stone, gravel, etc. for a public project. | A description of the excavation site before, during, and after activities; a brief mining plan and an environmental impact summary; BLM formally approves the plans. |

REQUIREMENTS RELATED TO BIOLOGICAL ASPECTS

| Endangered Species Act 16 USC 1531 et seq., Federal Land Management Policy Act (USFWS, DOI). Biological opinion on threatened and endangered species. | Construction and operation activities affecting flora and fauna. | A project description, a biological survey, and a report of findings; USFWS approves the information in writing. |
| Sikes Act, P.L. 93-452 (16 USC 679 et seq., (BLM). Consultation. | Construction activities within BLM and State Wildlife Agency Wildlife Habitat areas. | As above, USFWS action required. |

Table 6-9. Preliminary summary of Federal environmental regulatory
requirements that may apply to a repository at Yucca
Mountain (See footnotes at the end of the table) (continued)

Authority	Project Feature	Substantive Requirements

REQUIREMENTS RELATED TO BIOLOGICAL ASPECTS (continued)

Authority	Project Feature	Substantive Requirements
Migratory Bird Treaty Act, 16 USC 703-710 (50 CFR 10.13)	Act prohibits killing, capturing, transporting, etc., protected migratory birds, their nests, and eggs.	Project activities must avoid harm (including indirect effects) to migratory birds, their nests, and eggs.
Bald and Golden Eagle Protection Act, 16 USC 668-668d.	Act prohibits possessing, killing, transporting, disturbing, etc., bald and golden eagles, their nests, or eggs.	Project activities must avoid negative impacts to bald and golden eagles and their nests and eggs. Secretary of Interior may permit relocation of golden eagle nests if they interfere with resource development or recovery plans.
Wild Free-Roaming Horses and Burros Act, 16 USC 1331-1340 (43 CFR 4700).	Act protects all unbranded and unclaimed horses and burros on public lands of the United States.	Project activities must avoid harm (including indirect effects) to wild, free-roaming horses and burros on public lands.
National Wildlife Refuge System Administration Act of 1966, 16 USC Sections 668dd-668ee (50 CFR Parts 25, 27, 28, and 29).	Project activities that would conflict with the protection and conservation of national wildlife refuges.	A description of the project, the land to be disturbed and a summary report on the environmental impacts.

Table 6-9. Preliminary summary of Federal environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at the end of the table) (continued)

Authority	Project Feature	Substantive Requirements

REQUIREMENTS OR PERMITS RELATED TO AIR SPACE

Authority	Project Feature	Substantive Requirements
Federal Aviatior Act, 49 USC 1347 et seq., (FAA)[o]. Airspace Permit.	Buildings, towers, or other structures exceeding 200 ft in height.	A description of activities showing structures over 200 ft; FAA approves a formal application form.

[a]USC = United States Code.
[b]BLM = Bureau of Land Management.
[c]USFS = U.S. Forest Service.
[d]USFWS = U.S. Fish and Wildlife Service.
[e]DOI = U.S. Department of Interior.
[f]DOT = U.S. Department of Transportation.
[g]CFR = Code of Federal Regulations.
[h]DOE = U.S. Department of Energy.
[i]DOA = U.S. Department of Agriculture.
[j]EPA = U.S. Environmental Protection Agency.
[k]NAAQS = National Ambient Air Quality Standard.
[l]ACOE = Army Corps of Engineers.
[m]BIA = Bureau of Indian Affairs.
[n]NPS = National Park Service.
[o]FAA = Federal Aviation Authority.

Table 6-10. Preliminary summary of State environmental regulatory
requirements that may apply to a repository at Yucca Mountain
(See footnotes at end of table)

Authority	Project feature	Substantive requirements
REQUIREMENTS RELATED TO WATER		
NRS[a] Chapter 445.131 through 445.354; National Pollutant Discharge Elimination System Permit NDEP[b]; EPA[c] Region IX San Francisco.	Any activity that may result in a discharge of pollutants into State waters (either surface or underground).	Discharge quantity and water quality data, data on receiving waters and and impacts; EPA approves application form.
NRS Chapter 533 and 534; Permit to appropriate the Public Waters; NDWR[d].	Location of point of diversion and place of use, use for water, annual consumption of water.	Intake (well) specifications, location, and use; Nevada approves application form.
REQUIREMENTS RELATED TO SAFETY		
NRS 618; Construction and Operating Permit for New Elevators, Dumbwaiters and Moving Walks; NDOSH[e].	Assembly, installation, testing, and inspection of elevators, dumbwaiters, and moving walks.	Description of facility; Nevada approves Health and Safety Plan.
NRS 618; Boiler or Pressure Vessel Operating Permit; NDOSH.	Operation of a boiler or pressure vessel.	Description of facility; Nevada approves the permit application.
REQUIREMENTS RELATED TO LAND USE		
NRS 278, 439.200, 444, 445, and 446; Permit to Construct a Campsite; NDH[f] (Bureau of Consumer Health Protection Services).	Construction of labor camps, public bathing places, mobile home parks, camp kitchen & dining room, drinking water supply, recreational vehicle park, sewage system, or subdivision.	Specifications on all facilities; Nevada approves various application forms.

Table 6-10. Preliminary summary of State environmental regulatory
requirements that may apply to a repository at Yucca Mountain
(See footnotes at end of table) (continued)

Authority	Project feature	Substantive requirements
	REQUIREMENTS RELATED TO LAND USE (continued)	
NRS Chapter 512.160; Opening and Closing Mines; NSIM[g].	Opening and closing mining operations.	A notification form to be filed with the Inspector of Mines; Nevada approves form.
NRS Chapter 535; Permit to Construct Tailing Dam; if fresh-water storage, a Storage Permit is also required; NDWR.	Any tailing dam that is higher than 10 feet or or will impound more than 10 acre-feet.	Specifications on the dam and water relocation and drainage system; Nevada approves plans.
NRS Chapter 444.440 through 444.620; Solid Waste Management System; NDEP.	Any place where solid waste is dumped, abandoned, accepted, or disposed of by incineration, land filling, composting, or any other method. (This does not prevent a mining operation from dumping waste from its operation on its own land.)	Description of activities; Nevada approves plans.
NRS 322; Lease-Easement; NDSL[h].	The construction of bridges, pipelines, and water or sewer lines.	Facility specifications and description of construction activities; Nevada approves plans.
NRS 459.010 through 459.290; Radioactive Materials License; NDH (Bureau of Consumer Health Protection Services).	The use, storage, disposal, and extraction of certain nonexempt radioactive materials.	Description of materials, uses, and handling methods and procedures; Nevada approves license application.
NRS 444.700 through 444.778; Hazardous Waste Management; NDEP.	Storage, generation, transportation, treatment and disposal of hazardous waste.	See Federal Resource Conservation and Recovery Act.

Table 6-10. Preliminary summary of State environmental regulatory requirements that may apply to a repository at Yucca Mountain (See footnotes at end of table) (continued)

Authority	Project feature	Substantive requirements
REQUIREMENTS RELATED TO LAND USE (continued)		
Federal Regulations; Coordination; NDHPA[i].	Historic preservation.	See Federal Cultural Resources Section, Table 6-9.
NAC[j] 504.510 through 504.550; Special Permit--Modification of Habitat; NDW[k].	Any action that will change or alter wild life habitat, including thermal pollution.	Description of proposed activity and environmental impacts; Nevada approves activity in writing.
REQUIREMENTS RELATED TO AIR QUALITY		
NRS Chapter 445.401 through 445.601; Air Quality--Permit to Construct (Registration Certificate); NDEP.	Any boiler over 4 million BTU, incinerators, mining operations, asphalt plants, cement plants, and other industrial processes.	Application form and support data including emissions, engineering equipment specifications, meteorology data, dispersion modeling, effects to environment compared with NAAQS[l] and PSD[m] standards; Nevada approves application form.
NRS Chapter 445.401 through 445.601; Air Quality--Permit to Operate; NDEP.	Compliance with construction permit within 180 days of startup of facility.	As above.
NRS Chapter 445.401 through 445.601; Air Quality--Prevention of Significant Deterioration; NDEP.	Major stationary sources (28 categories) and any source that emits greater than 250 tons/yr of a major pollutant.	As above.

Table 6-10. Preliminary summary of State environmental regulatory
requirements that may apply to a repository at Yucca Mountain
(See footnotes at end of table) (continued)

Authority	Project feature	Substantive requirements
REQUIREMENTS RELATED TO AIR QUALITY (continued)		
NRS 445.401 through 445.601; Air Quality--Permit to Construct (Registration Certificate) or Permit to operate; NDEP.	Any surface disturbance of 8 hectares (20 acres) or more; clearing, leveling, excavating or for the deposit of any foreign material to fill or cover such land.	As above.

^aNRS = Nevada Revised Statutes.
^bNDEP = Nevada Division of Environmental Protection.
^cEPA = Environmental Protection Agency.
^dNDWR = Nevada Division of Water Resources.
^eNDOSH = Nevada Division of Occupational Safety and Health.
^fNDH = Nevada Department of Health.
^gNSIM = Nevada State Inspector of Mines.
^hNDSL = Nevada Division of State Lands.
ⁱNDHPA = Nevada Division of Historic Preservation and Archaeology.
^jNAC = Nevada Administrative Code.
^kNDW = Nevada Department of Wildlife.
^lNAAQS = National Ambient Air Quality Standard.
^mPSD = Prevention of Significant Deterioration.

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Table 6-10. Preliminary summary of State environmental regulatory
requirements that may apply to a repository at Yucca Mountain
(See footnotes at end of table) (continued)

Authority	Project feature	Substantive requirements
REQUIREMENTS RELATED TO AIR QUALITY (continued)		
NRS 445.401 through 445.601; Air Quality--Permit to Construct (Registration Certificate) or Permit to operate; NDEP.	Any surface disturbance of 8 hectares (20 acres) or more; clearing, leveling, excavating or for the deposit of any foreign material to fill or cover such land.	As above.

[a] NRS = Nevada Revised Statutes.
[b] NDEP = Nevada Division of Environmental Protection.
[c] EPA = Environmental Protection Agency.
[d] NDWR = Nevada Division of Water Resources.
[e] NDOSH = Nevada Division of Occupational Safety and Health.
[f] NDH = Nevada Department of Health.
[g] NSIM = Nevada State Inspector of Mines.
[h] NDSL = Nevada Division of State Lands.
[i] NDHPA = Nevada Division of Historic Preservation and Archaeology.
[j] NAC = Nevada Administrative Code.
[k] NDW = Nevada Department of Wildlife.
[l] NAAQS = National Ambient Air Quality Standard.
[m] PSD = Prevention of Significant Deterioration.

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Waste Policy Act of 1982 (NWPA, 1983). The DOE intends to consult with appropriate State and local officials concerning sites that are recommended to determine the scope of the above noted requirements and identify other regulations as appropriate.

Assumptions and data uncertainties

The assumptions and uncertainties in the data used to evaluate the environmental quality guideline result from having only preliminary design studies available for the exploratory shaft and repository at Yucca Mountain (see chapters 4 and 5). Because only preliminary information is available, the evaluation of environmental impacts must also be considered preliminary. Specific assumptions and uncertainties in the data used to evaluate this technical guideline are described in chapters 4 and 5.

Assessing the significance of environmental impacts also has inherent uncertainties because of uncertainties in the criteria and the validity of the assumptions used to evaluate the significance of the environmental impacts. In general, easily verifiable impacts, such as irreconcilable conflicts with the designated uses of federally protected lands, can be evaluated with a high degree of certainty because the significance of the impact is defined clearly. In contrast, the significance of the effects exerted by the siting, construction, and operation of a repository on ground water or biotic communities is generally less certain. In estimating the significance of such potential environmental impacts that cannot be defined precisely, it is necessary to rely on the judgment of environmental specialists. The uncertainties will be minimized through ongoing investigations, the results of which will be described in an environmental impact statement if Yucca Mountain is selected as a site for further study (site characterization).

6.2.1.6.3 Favorable conditions

(1) Projected ability to meet, within time constraints, all Federal, State, and local procedural and substantive environmental requirements applicable to the site and the activities proposed to take place thereon.

Evaluation

A preliminary list of Federal and State environmental requirements that currently exist and may apply to the siting, construction, operation, closure, and decommissioning of a repository at Yucca Mountain is given in tables 6-9 and 6-10 (there are no applicable local environmental requirements). In some instances, the cited authority may require the U.S. Department of Energy (DOE) to obtain several different types of permits; in other instances the authority may require the DOE to consult with or notify the appropriate agency. A preliminary evaluation of the listed environmental requirements with regard to the site information presented in Chapter 3 and the potential environmental impacts presented in chapters 4 and 5 has been conducted. In addition, the DOE intends to comply with all State and local environmental requirements not inconsistent with the DOE responsibilities under the Nuclear Waste Policy Act (the Act) of 1982 (NWPA, 1983) as a matter of policy.

Conclusion

On the basis of the site information presented in Chapter 3 and the currently proposed activities and associated potential impacts as presented in chapters 4 and 5 evaluated with respect to current Federal, State, and local environmental requirements, no reason has been identified that would suggest that such requirements cannot be met, within time constraints, during the siting, construction, operation, closure, and decommissioning of a repository at the Yucca Mountain site. It has been assumed in this evaluation that current requirements would be interpreted and applied consistently with historical interpretation and application to activities of a similar scope and impact and that future requirements would not be inconsistent with the DOE responsibilities under the Act. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

> (2) Potential significant adverse environmental impacts to present and future generations can be mitigated to an insignificant level through the application of reasonable measures, taking into account programmatic, technical, social, economic, and environmental factors.

Evaluation

The adverse environmental impacts associated with the siting, construction, operation, closure, and decommissioning of a repository at Yucca Mountain are described in chapters 4 and 5. The major impact associated with site-characterization activities would be the disturbance of approximately 285 hectares (705 acres) of wildlife habitat. Other impacts include increased emissions of hydrocarbons and particulates and increased noise levels. Table 4-6 provides a summary of the environmental effects associated with site characterization. The impacts related to the repository include (1) the destruction of approximately 680 hectares (1,680 acres) of desert habitat, (2) fugitive-dust emissions, (3) vehicle emissions, and (4) radiation releases during the excavation and operation of the repository, and possibly from accidents. Radionuclide releases to the ground water in excess of limits set by 40 CFR Part 191 (1985) are not expected during operation or for thousands of years after decommissioning (Section 6.4). The significance of impacts to the biota from repository construction and operation are described in the evaluation of potentially adverse condition 6.

Emissions of fugitive dust will result from surface preparation, excavation, and the manipulation of the excavated rock and soil during the construction, operation, closure (backfilling), and decommissioning of the repository. Dust emissions will also result from the disturbance of approximately 486 hectares (1,200 acres) during the construction of a railroad to the repository, and from the disturbance of 79 hectares (195 acres) during the construction of an access road from U.S. Highway 95 north to the site. Carbon monoxide, hydrocarbons, and oxides of sulfur and nitrogen will be released from construction equipment and from private vehicles that transport workers to and from the site.

During repository construction, the emission rate and predicted impacts for particulates, carbon monoxide, hydrocarbons, and oxides of sulfur and nitrogen are not expected to exceed the air-quality limits of 40 CFR Part 50

(1983) at the boundary of the controlled area. Section 5.2.5 describes the models used to estimate the pollutants expected from repository construction, assuming no dust-suppression measures are taken. These models predict total suspended particulates of 130 micrograms per cubic meter for a ridge location and 132 micrograms per cubic meter for a valley location (Table 5-14). These concentrations are below the fugitive-dust standards in 40 CFR Part 50 (1983), which specify that a maximum allowable 24-hour concentration of 260 micrograms per cubic meter should not be exceeded more than once per year (Table 5-10). Section 5.2.5 provides a more complete discussion of air-quality regulations and estimated impacts. If the project is subject to Prevention of Significant Deterioration provisions of the Clean Air Act Amendments of 1977, the predicted pollutant concentrations would violate none of the applicable standards.

The release of naturally occurring radon and decay products from the volcanic rocks of Yucca Mountain will increase during repository excavation and during the manipulation of the excavated soil and rock (Table 5-22). Using estimates of natural radiation in granite (DOE, 1980a), an estimate of the release of natural radioactivity from the volcanic rocks of the Yucca Mountain site during construction can be calculated. Construction of a repository would result in an annual effective whole-body dose for a member of the general population of less than 0.05 millirem. Natural background radiation from all sources contributes an individual whole-body equivalent dose of 0.09 rem per year (Jackson et al., 1984). Routine releases from radon in the surface spoils piles during backfilling are expected to be negligible. The above estimates indicate that the environmental impact from radiological releases during excavation of the repository is not significant. See Section 6.4.1 for discussions of expected releases during normal repository operation, which are expected to represent less than 2 percent of natural background radiation.

Conclusion

No potential significant adverse environmental impacts to present or future generations have been identified from the siting, construction, operation, closure, and decommissioning of a repository at Yucca Mountain. Consequently, additional mitigation over that currently proposed is not required. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

6.2.1.6.4 Potentially adverse conditions

(1) <u>Projected major conflict with applicable Federal, State, or local environmental requirements.</u>

Evaluation

The U.S. Department of Energy (DOE) will be required to obtain all applicable permits. Lists of the environmental regulations that may apply to siting, construction, operation, closure, or decommissioning of a repository at Yucca Mountain are given in tables 6-9 and 6-10. No major conflict with applicable Federal, State, or local environmental requirements is expected.

Conclusion

It is expected that all applicable Federal, State, and local environmental requirements will be satisfied. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(2) Projected significant adverse environmental impacts that cannot be avoided or mitigated.

Evaluation

The basis for concluding that the environmental impacts that would stem from siting, constructing, operating, closing, or decommissioning a repository at Yucca Mountain can be mitigated or avoided is given in the evaluation sections of favorable condition 2, potentially adverse condition 6, and in chapters 4 and 5.

Conclusion

The adverse environmental impacts expected from the siting, construction, operation, closure, and decommissioning of a repository can be mitigated to an acceptable degree or avoided. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(3) Proximity to, or projected significant adverse environmental impacts of the repository or its support facilities on, a component of the National Park System, the National Wildlife Refuge System, the National Wild and Scenic Rivers System, the National Wilderness Preservation System, or National Forest Land.

Evaluation

As discussed in Section 6.2.1.3, the surface and underground facilities at Yucca Mountain would be located entirely on Federal lands currently administered by the DOE and the U.S. Department of the Air Force (DAF) as well as public-domain lands under the jurisdiction of the Bureau of Land Management (BLM). As noted in the relevant data of Section 6.2.1.3, the proposed facilities would be located on Federal lands that are not currently restricted by environmental land-use considerations.

If a repository is located at Yucca Mountain, the proposed rail line would be constructed from Yucca Mountain to a point a few miles northeast of Las Vegas (see map of proposed rail routing, Chapter 5, Figure 5-2) and a paved access road would be built from U.S. Highway 95 approximately 25 kilometers (16 miles) northward to the site. At some points, the rail line may be within the vicinity of the southern boundary of the Desert National Wildlife Range (Lutsey and Nichols, 1972). Large parts of the wildlife range are administratively endorsed as suitable for inclusion in the National Wilderness Preservation System (BLM, 1983). The effects on the Desert National Wildlife Range due to the construction and operation of the rail line are expected to be minor because the rail line is not expected to traverse lands within the wildlife range. The proposed access route from

U.S. Highway 95 to the site would be entirely on federally controlled land with no conflicting uses.

The boundary of Death Valley National Monument lies approximately 30 to 40 kilometers (20 to 25 miles) west and southwest of the Yucca Mountain site (Lutsey and Nichols, 1972). The environmental effects of siting, constructing, and operating a repository at Yucca Mountain include increased use of the monument by the construction workers and the employees of the repository. This could produce some effect on the facilities and scenic attributes of the monument, but the significance of these impacts is expected to be minor.

The northern part of the controlled area surrounding the repository site would be approximately 8 kilometers (5 miles) south of the Timber Mountain Caldera National Natural Landmark. This federally designated landmark would not be disturbed during the construction and operation of the repository. Furthermore, the landmark is located within the Nellis Air Force Range and the Nevada Test Site, and access to it is restricted.

Recently, the U.S. Fish and Wildlife Service (USFWS) purchased 5,121 hectares (12,654 acres) of private land in the Ash Meadows area from the Nature Conservancy and has established the area as a unit within the National Wildlife Refuge System. In addition, Devils Hole is protected as part of Death Valley National Monument. The Ash Meadows area is located about 40 kilometers (25 miles) from Yucca Mountain. Relict populations of pupfish and many unusual endemic plants exist in the spring habitats of Ash Meadows including: four species of fish listed as endangered by the USFWS, Devils Hole pupfish, Cyprinodon diabolis; Warm Springs pupfish, Cyprinodon nevadensis pectoralis; Ash Meadows Amargosa pupfish, Cyprinodon nevadensis mionectes; and Ash Meadows speckled dace, Rhinichthys osculus nevadensis (USFWS, 1983a); an endangered plant, Amaragosa niterwort, Nitrophila mohavensis; six threatened plants, Ash Meadows ivesia, Ivesia eremica; Ash Meadows sunray, Enceliopsis nudicaulis var. corrugata; spring-loving centaury, Centaurium namophilum; Ash Meadows blazing star, Mentzelia leucophylla; Ash Meadows milk vetch, Astragalus phoenix; and Ash Meadows gumplant, Grindelia fraxinopratensis; and a threatened insect, Ash Meadows naucorid, Ambrysus amargosus (DOI, 1984). Eight species of endemic molluscs are candidates for possible listing as endangered or threatened species in the future (DOI, 1984), and the Ash Meadows vole (Microtus montanus nevadensis) has been classified as a Category 2 mammal which is being reviewed for possible addition to the list (DOI, 1984).

Analysis of studies by Dudley and Larson (1976) and Waddell (1982) suggest that the construction and operation of a repository at Yucca Mountain will not affect the outflow of the springs at Ash Meadows, because water supplies for the repository will not be drawn from the ground-water basin that feeds the springs. Potential environmental impacts to this refuge from repository workers are projected to be negligible because land use in the area would be restricted by the USFWS.

Conclusion

The proposed repository and its supporting facilities, including a rail line that may be constructed in southern Nevada and a paved road that may be

constructed from U.S. Highway 95 northward to Yucca Mountain, would not result in any significant adverse environmental effects on federally protected lands (e.g., parks, monuments, recreation areas, wildlife areas, wilderness areas), or lands administered by the U.S. Forest Service. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(4) Proximity to, and projected significant adverse environmental impacts of the repository or its support facilities on, a significant State or regional protected resource area, such as a State park, a wildlife area, or a historical area.

Evaluation

The surface and underground facilities at Yucca Mountain would be located entirely on Federal lands currently administered by the DOE and the DAF, as well as public-domain lands under the jurisdiction of the BLM (Lutsey and Nichols, 1972). If a repository is constructed at Yucca Mountain, a 161-kilometer (100-mile) rail line may be built to the site from Dike Siding a few miles northeast of Las Vegas. The proposed rail line would pass within 1.4 kilometers (0.9 miles) of Floyd R. Lamb State Park (formerly called Tule Springs Park; sections 3, 4, and 9, T. 19 S., R. 60 E.). The composite annual day and night (L_{dn}) noise levels induced in the park by the construction and the operation of the rail line would be below U.S. Environmental Protection Agency limits (Section 5.2.6.1). Therefore, significant adverse impacts to this State Park are not expected from the construction and operation of a rail line in this area.

Conclusion

The repository and its proposed supporting facilities, including a railroad that would be constructed in southern Nevada and a paved road that would be constructed from U.S. Highway 95 northward to Yucca Mountain, would not exert significant adverse environmental impacts on State protected lands, such as parks, recreation areas, or wildlife areas. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(5) Proximity to, and projected significant adverse environmental impacts of the repository and its support facilities on, a significant Native American resource, such as a major Indian religious site, or other sites of unique cultural interest.

Evaluation

Most of the Yucca Mountain site has been surveyed for cultural artifacts by Pippin et al. (1982). Limited test excavations were conducted of 178 prehistoric and 6 historic sites (Pippin, 1984), many of which consist of only flakes and scattered debris. Archaeological surveys have not yet been conducted along the proposed railroad corridor or along the paved road that would be constructed to Yucca Mountain from U.S. Highway 95.

Artifacts at those sites that cannot be preserved during siting and construction, or protected during operation will, upon approval of the Nevada

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State Historic Preservation Office, be collected and catalogued. These
artifacts, along with a record of the physical setting where they were found,
can then be described and displayed in museums. Thus, although some sites
may be affected by the construction of the repository, the artifacts and
information contained at these sites will be recorded and preserved.

Conclusion

The siting, construction, and operation of the repository are not
expected to have an effect on significant Native American resources or unique
cultural resources in this region. Although some archaeological and
historical sites may be affected by the construction of the repository, the
Nevada State Historical Preservation Office will be informed before construc-
tion begins so that artifacts at these sites can be collected and catalogued.
Therefore, the evidence indicates that this potentially adverse condition is
not present at Yucca Mountain.

(6) Presence of critical habitats for threatened or endangered
species that may be compromised by the repository or its support
facilities.

Evaluation

Surveys to date indicate that no threatened or endangered plant or
animal species, or their critical habitats, occur in the Yucca Mountain area,
although a State protected species is found in the area.

Two species found in the Yucca Mountain area (O'Farrell and Collins,
1983) are currently under review by the USFWS as candidates for inclusion in
the Federal list of threatened species. They are the Mojave fishhook cactus
(Sclerocactus polyancistrus) and the desert tortoise (Gopherus agassizii).
The desert tortoise is also a State protected species and is designated as a
rare species. Also, preliminary analyses show that the desert tortoise
population in the Yucca Mountain area is low in comparison with other areas
in the southwestern United States (O'Farrell and Collins, 1983). During
repository construction and operation individual tortoises may be transported
from the disturbed areas to remote undisturbed locations. The survival of
these relocated animals, however, is uncertain, and some of the habitat for
the species would be destroyed during repository construction. Efforts
consistent with economic and safety considerations will be made to avoid
dense populations of the cactus and important habitats for the tortoise. The
technique for relocating tortoises will be investigated further before any
relocation occurs.

As discussed in the evaluation of potentially adverse condition 3,
several species have been listed as threatened or endangered, and others in
Ash Meadows have been proposed for future listing. Analyses of studies by
Dudley and Larson (1976) and Waddell (1982) suggest that repository siting,
construction, operation, and closure at Yucca Mountain should not affect the
outflow of the springs in Ash Meadows. Water supplies for the repository
will not be drawn from the ground-water basin that feeds the springs.
Existing land-use restrictions in the area surrounding the springs and in the
ground-water basin that supplies the springs should prevent indirect impacts

on the water supply from workers moving into the area and also should help to
protect the habitats of the proposed endangered species.

Conclusion

The siting, construction, and operation of a repository and its
supporting facilities are not expected to have a significant adverse effect
on the Mojave fishhook cactus, the desert tortoise, or the Ash Meadows
ecosystem. In addition, present land-use restrictions in Ash Meadows and
regulation of the surrounding ground-water basin will help to protect the
habitat of the endangered species found there. Therefore, the evidence
indicates that this potentially adverse condition is not present at Yucca
Mountain.

6.2.1.6.5 Disqualifying conditions

There are three disqualifying conditions with regard to environmental
quality. The disqualifying conditions in this guideline (stated below) are
evaluated together to avoid repetition. Separate conclusions are given for
each disqualifying condition.

Any of the following conditions shall disqualify a site:

(1) During repository siting, construction, operation, clo-
sure, or decommissioning, the quality of the environment in
the affected area could not be adequately protected or pro-
jected environmental impacts in the affected area could not be
mitigated to an acceptable degree, taking into account
programmatic, technical, social, economic, and environmental
factors.

(2) Any part of the restricted area or repository support
facilities would be located within the boundaries of a
component of the National Park System, the National Wildlife
Refuge System, the National Wilderness Preservation System, or
the National Wild and Scenic Rivers System.

(3) The presence of the restricted area or the repository
support facilities would conflict irreconcilably with the
previously designated resource-preservation use of a component
of the National Park System, the National Wildlife Refuge
System, the National Wilderness Preservation System, the
National Wild and Scenic Rivers System, or National Forest
Lands, or any comparably significant State protected resource
that was dedicated to resource preservation at the time of the
enactment of the Act.

Evaluation

The adverse environmental impacts that may be associated with the
siting, construction, operation, closure, and decommissioning of a repository
at Yucca Mountain are thoroughly described in chapters 4 and 5. The major

impact associated with site-characterization activities would be the disturbance of approximately 285 hectares (705 acres) of wildlife habitat. The impacts related to the repository include (1) the disruption of over 680 hectares (1,680 acres) of desert habitat, (2) fugitive-dust emissions, (3) vehicle emissions, and (4) radiation releases during the excavation and the operation of the repository and possibly from accidents at the repository.

Approximately 680 hectares (1,680 acres) of land will be cleared for the repository and for the supporting transportation facilities in southern Nevada. Surveys to date (O'Farrell and Collins, 1983) indicate that no threatened or endangered plant or animal species, or their critical habitats, occur in the immediate area of the Yucca Mountain site. However, the Mojave fishhook cactus (Sclerocactus polyancistrus) and the desert tortoise (Gopherus agassizii), which are found in the Yucca Mountain area, are currently under review by the U.S. Fish and Wildlife Service (USFWS) as candidates for inclusion in the Federal list of threatened species. The desert tortoise is also a State protected species and is designated as a rare species. Preliminary analyses show that the desert tortoise population is low in the area of the Yucca Mountain site. Tens of thousands of acres of undisturbed habitat will surround the repository site. During repository siting, construction, operation, and closure, individual tortoises may be transported to remote undisturbed locations. Where possible, populations of the cactus and locations of known tortoise habitat identified during preconstruction surveys will be avoided.

Fugitive-dust emissions will result from surface preparation, excavation, and the manipulation of the excavated soil and rocks during siting, construction, operation, closure, and decommissioning. Dust emissions will also result from the disturbance of approximately 486 hectares (1,200 acres) during the construction of a rail line to the repository and the disturbance of 79 hectares (195 acres) during construction of an access road from U.S. Highway 95. During repository construction, the emission rate and predicted impacts for particulates, carbon monoxide, and oxides of sulfur and nitrogen are not expected to exceed the air-quality limits of 40 CFR Part 50 (1983) at the boundary of the controlled area. Table 5-14 and Section 5.2.5 discuss pollutants expected from repository construction, assuming no dust-suppression measures are taken. Total suspended particulates of 130 micrograms per cubic meter are estimated for a ridge location, and 132 micrograms per cubic meter are estimated for a valley location. These concentrations are below the total suspended particulate standards in 40 CFR Part 50 (1983) which specify that a maximum allowable 24-hour concentration of 260 micrograms per cubic meter should not be exceeded more than once per year. Section 5.2.5 provides a more complete discussion of air-quality regulations and estimated impacts. If the Project is subject to Prevention of Significant Deterioration provisions of the Clean Air Act Amendments of 1977, the predicted pollutant concentrations would violate none of the applicable standards.

The release of naturally occurring radon and decay products from the volcanic rocks of the Yucca Mountain site will increase during repository excavation and during the manipulation of the excavated rock and earth. Using estimates of natural radiation in granite (DOE, 1980a), an estimate of the release of natural radioactivity from the volcanic rocks of the Yucca

Mountain site during construction can be calculated. Construction of a repository would result in an annual effective whole-body dose for a member of the general population of less than 0.05 millirem. Natural background radiation from all sources contributes an individual whole-body equivalent dose of 0.09 rem per year (Jackson et al., 1984). Routine releases of radon from the excavated rock and earth during backfilling are expected to be negligible. On the basis of the above estimates, the environmental impacts from radiological releases during excavation are not expected to be significant. Section 6.4.1 discusses radioactive releases during normal repository operations. The largest release is predicted for krypton-85 (see Table 6-46), giving an air concentration of 6.3×10^{-8} curies per cubic meter which represents only 0.009 percent of the maximum permissible concentrations specified in 10 CFR Part 20 (1984). Dispersion between the discharge point and the site boundary would reduce the krypton-85 concentratin to below the maximum permissible concentration specified in 10 CFR Part 20 (1984).

The surface and underground facilities at Yucca Mountain would be located entirely on Federal lands currently administered by the U.S. Department of Energy (DOE) and the Department of the Air Force, as well as public-domain lands under the jurisdiction of the Bureau of Land Management. None of these lands are protected for environmental reasons. A railroad may be constructed from Dike Siding, 18 kilometers (11 miles) northeast of Las Vegas, to Yucca Mountain. At some localities along this proposed route, the rail line would be within a few miles of the southern boundary of the Desert National Wildlife Range, part of which has been administratively endorsed as suitable for inclusion in the National Wilderness Preservation System. The effects exerted on the wildlife range by construction and operation of the railroad, even assuming that part of the range is ultimately included in the Wilderness Preservation System, are expected to be insignificant because the rail line is not expected to cross the range.

The boundary of the Death Valley National Monument lies 30 to 40 kilometers (20 to 25 miles) west and southwest of the Yucca Mountain site. The environmental effects of siting, constructing, operating, closing, and decommissioning a repository at Yucca Mountain include increased use of the monument by the construction workers and the employees of the repository. Ash Meadows, located about 40 kilometers (25 miles) from Yucca Mountain, contains plants and animals which have been listed as threatened or endangered species by the USFWS, as well as species proposed for future listing as threatened or endangered species. The outflow of the springs at Ash Meadows is not expected to be affected by the construction and operation of a repository at Yucca Mountain because water supplies for the site will be extracted from a different ground-water basin, as shown by the regional flow models given by Waddell (1982). The USFWS recently purchased 5,121 hectares (12,654 acres) of land in the vicinity of Devils Hole and established this land as a unit within the National Wildlife Refuge System. This action should serve to further restrict potential land use by repository workers in the Ash Meadows area.

The northern part of the controlled area surrounding the repository site would be approximately 8 kilometers (5 miles) south of the Timber Mountain Caldera National Natural Landmark. This federally designated landmark would not be disturbed during the construction and operation of the repository.

Furthermore, because the landmark is located within the Nellis Air Force Range and the Nevada Test Site, access to it has been, and will continue to be, restricted. The northern part of the Toiyabe National Forest is about 80 kilometers (50 miles) southeast of the Yucca Mountain site. It is unlikely that this National forest will be affected by repository development because of its distance from Yucca Mountain.

Conclusion for disqualifying condition 1

On the basis of preliminary evaluations, the siting, construction, operation, closure, and decommissioning of a repository at Yucca Mountain would not result in any unacceptable adverse environmental impacts that could not be mitigated to an acceptable degree. Therefore, the evidence does not support a finding that the site is disqualified (level 1).

Conclusion for disqualifying condition 2

Neither the restricted area nor the supporting facilities for a repository at Yucca Mountain would be located within the boundaries of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, or the Wild and Scenic Rivers System. Therefore, the evidence supports a finding that the site is not disqualified on the basis of that evidence and is not likely to be disqualified (level 1).

Conclusion for disqualifying condition 3

Neither the restricted area nor the supporting facilities for a repository at Yucca Mountain would irreconcilably conflict with the previously designated resource-preservation use of a component of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, the National Wild and Scenic Rivers System, or National Forest Lands, or any comparably significant State protected resource. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is disqualified (level 1).

6.2.1.6.6 Evaluation and conclusion for the qualifying condition on the environmental quality guidelines

Evaluation

Chapters 4 and 5 provide preliminary assessments of the potential for adverse environmental impacts from the siting, construction, operation, closure, and decommissioning of a repository at Yucca Mountain. These preliminary studies indicate that no potentially significant adverse environmental impacts that could not be mitigated to an acceptable degree should be expected from the siting, construction, operation, closure, and decommissioning of a repository at Yucca Mountain. The quality of the environment during this and future generations can be adequately protected. Estimates of radiation releases during normal operation and worst-case accident scenarios provide confidence that the public and the environment can be adequately protected from the potential hazards of radioactive-waste disposal.

No major conflict with applicable Federal, State, and local environmental requirements is expected. The adverse environmental impacts expected from repository siting, construction, operation, closure, and decommissioning can either be avoided or mitigated to an acceptable degree by reasonable and inexpensive methods. The repository and its supporting facilities, including a rail line and roads, would not result in any significant adverse environmental impacts on Federal or State protected lands or any known threatened or endangered species or their habitats.

Conclusion

The environment can be protected during the siting, construction, operation, closure, and decommissioning of a repository at Yucca Mountain. No potentially significant adverse environmental impacts have been identified. The requirements specified in 10 CFR 960.5-1(a)(2) (1984) for protection of the public and the environment from the potential hazards posed by the disposal of radioactive waste are expected to be met without undue difficulty. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for environmental quality (level 3).

6.2.1.7 Socioeconomic impacts (10 CFR 960.5-2-6)

6.2.1.7.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall be located such that (1) any significant adverse social and/or economic impacts induced in communities and surrounding regions by repository siting, construction, operation, closure, and decommissioning can be offset by reasonable mitigation or compensation, as determined by a process of analysis, planning, and consultation among the DOE, affected State and local government jurisdictions, and affected Indian tribes; and (2) the requirements specified in Section 960.5-1(a)(2) can be met.

The preclosure socioeconomics technical guideline is concerned with (1) the interaction between repository-related activities and the existing economic, demographic, and social conditions of the area during the siting, construction, operation, closure, and decommissioning of the repository and (2) the reasonable mitigation or compensation for associated significant adverse impacts.

The guideline contains four favorable conditions, four potentially adverse conditions, one disqualifying condition, and one qualifying condition. Table 6-11 summarizes the pertinent findings for all conditions except the disqualifying condition.

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Table 6-11. Summary of analyses for Section 6.2.1.7; socioeconomic impacts (10 CFR 960.5-2-6)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITIONS	
(1) Ability of an affected area to absorb the project-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand.	The evidence indicates that this favorable condition is present at Yucca Mountain: projected population growth rates with the repository do not exceed historical rates; the area is expected to absorb changes without significant impacts.
(2) Availability of an adequate labor force in the affected area.	The evidence indicates that this favorable condition is not present at Yucca Mountain: an adequate total work force is expected to be available; the available work force with mining skills is expected to be inadequate; it is possible that the available construction work force may also be inadequate.
(3) Projected net increases in employment and business sales, improved community services, and increased government revenues in the affected area.	The evidence indicates that this favorable condition is present at Yucca Mountain: the affected area is projected to have increased employment and business sales; community services could be improved and government revenues are likely to increase.
(4) No projected substantial disruption of primary sectors of the economy of the affected area.	The evidence indicates that this favorable condition is present at Yucca Mountain: Increased employment in the mining and construction sectors is not expected to cause substantial disruption; results of a preliminary study concerning the potential effect of a repository on tourism are inconclusive. However, analysis to date of cases examining the relationship of safety concerns to tourism concluded that long-term impacts were not apparent.

Table 6-11. Summary of analyses for Section 6.2.1.7; socioeconomic impacts (10 CFR 960.5-2-6) (continued)

Condition	Department of Energy (DOE) finding
POTENTIALLY ADVERSE CONDITIONS	
(1) Potential for significant repository-related impacts on community services, housing supply and demand, and the finances of State and local government agencies in the affected area.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: service providers in the area are expected to have the resources to deal with community-level growth rates, which are generally expected to be within the range experienced historically by urban communities and the two counties; significant repository-related impacts on government finances are, accordingly, not expected.
(2) Lack of an adequate labor force in the affected area.	The evidence indicates that this potentially adverse condition is present at Yucca Mountain: the available mining work force is expected to be inadequate; it is possible that the construction work force may be also; the total work force is expected to be adequate.
(3) Need for repository-related purchase or acquisition of water rights, if such rights could have significant adverse impacts on the present or future development of the affected area.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain; water rights are expected to provide sufficient water to support repository activities without adverse impacts on the rights of other water users in the region.

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Table 6-11. Summary of analyses for Section 6.2.1.7; socioeconomic impacts (10 CFR 960.5-2-6) (continued)

Condition	Department of Energy (DOE) finding

POTENTIALLY ADVERSE CONDITIONS (continued)

(4) Potential for major disruptions of primary sectors of the economy of the affected area.

The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: Information available to date does not suggest that the repository is likely to have significant effects on tourism; the expected increase in mining and construction employment is not considered to be a major disruption.

QUALIFYING CONDITION

The site shall be located such that (1) any significant adverse social and/or economic impacts induced in communities and surrounding regions by repository siting, construction, operation, closure, and decommissioning can be offset by reasonable mitigation or compensation, as determined by a process of analysis, planning, and consulting among the DOE, affected State and local government jurisdictions, and affected Indian Tribes; and, (2) the requirements specified in Section 960.5-1(a)(2) can be met.

Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): no unmitigable significant adverse social and/or economic effects have been identified in preliminary design and impact studies; the DOE is committed to working with State and local governments so that the public and the environment are protected from the hazards posed by the disposal of radioactive waste.

6.2.1.7.2 Data relevant to the evaluation

Preliminary evaluations of the socioeconomic impacts of siting, construction, operation, closure and decommissioning of a repository at Yucca Mountain are discussed in chapters 4 and 5. For purposes of this guideline, the affected region is defined to include Nye County, where the site is located, as well as neighboring Clark County. The U.S. Department of Energy intends to consider a larger geographic area in its study of potential impacts, if Yucca Mountain is nominated and approved for site characterization. However, the socioeconomic effects predicted for the two counties, where approximately 96 percent of the repository-related population are expected to settle, are indicative of the nature and extent of the total social and economic impact.

Information about the potential social and economic impacts of a repository at Yucca Mountain is contained in preliminary reports (McBrien and Jones, 1984; SAIC, 1985) describing previous and ongoing work on the regional and local impacts, including potential impacts on local tourism. The analyses and data in those reports as well as the analyses and data presented in chapters 3, 4, and 5 provide the basis for assessing the potential social and economic impacts of a repository at Yucca Mountain.

Assumptions and data uncertainties

The assumptions and analyses that form the basis for this evaluation appear in detail in sections 3.6, and 4.2.2, 5.1.5, and 5.4.

6.2.1.7.3 Favorable conditions

(1) Ability of an affected area to absorb the project-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand.

Evaluation

Detailed forecasts of community-level service capacity and housing supply and demand are not available. This evaluation considers impacts at the county level. Subsequent analyses will consider, in more detail, impacts on the incorporated cities in the bicounty area, and on other governmental units responsible for providing public services. Although it is recognized that the term significant disruptions may be defined differently by the U.S. Department of Energy (DOE) and local communities, for purposes of this analysis, county-level population changes were assumed to significantly affect community services and housing when the total population (baseline plus repository-related) increase in any year exceeds that historically experienced by the area.

In general the construction of the repository would require more workers and thus result in greater population increases than would the siting, operation, and decommissioning. However, because of the two-stage repository design, the construction and operation periods are expected to overlap

3 years. The maximum number of workers (approximately 1,900) would be needed in the sixth year of construction, which is also the first year of operations (1998) (Table 5-5a). The maximum 1-year percent increase in population would occur during the second year of construction (1994) (Table 5-47). This maximum 1-year increase is projected to be 3.7 percent for Clark County and 4.0 percent for Nye County. Without the repository, the population growth rate between 1993 and 1994 is projected to be 3.1 percent for Clark County and 2.1 percent for Nye County. Given previous population growth rates (tables 3-16 and 3-15), the affected area is expected to be able to absorb the repository-related population changes without significant disruptions in community services or significant impacts on housing supply and demand. As population increases, with or without the repository, certain areas of both counties are expected to experience water-supply problems (Section 5.4.3.3).

Evaluations of the extent and significance of future impacts are made through comparisons with past growth rates. These evaluations assume either that the historical growth did not result in significant impacts on housing and community services or that the responsible local governments have benefited from experience so that significant future impacts on community services and housing can be avoided. It is assumed that the DOE would work in cooperation with the responsible governmental entities to plan for increased demand for community services and housing and to develop monitoring, corrective action, and mitigation programs, which would include the provision of financial assistance as specified by the Nuclear Waste Policy Act (NWPA, 1983).

While past population growth provides the responsible governmental entities and the private sector with experience in planning for, and responding to, future growth, some impacts on housing and community services may occur regardless of the ability of these organizations to respond. These impacts may involve aesthetics; for example, a change in housing mix (e.g., more mobile homes) associated with growth may be regarded as undesirable by some community residents. Such aesthetic preferences are not uniform across communities. Individual community preferences will be explored in future research. As appropriate, the DOE, in consultation with local officials, would develop a plan to encourage or discourage workers from moving into specific communities. For example, this plan might include transportation subsidies for repository employees commuting along specific routes or the provision of housing.

Conclusion

The affected area, including the Las Vegas Valley, has the ability to absorb the repository-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand. This conclusion is based on the assumption that no 1-year population growth rate expected during the repository project would exceed historical population growth rates in the affected (i.e. bicounty) area. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(2) **Availability of an adequate labor force in the affected area.**

Evaluation

The peak number of direct workers expected during site characterization is 273. Approximately 50 percent of those are expected to be existing DOE and contractor employees (Section 4.2.2.1.1). The demand for additional site characterization workers from the existing work force is not expected to be significant. At peak, the repository construction/operation overlap would employ about 1,900 direct workers in 1998. One approach for evaluating the adequacy of labor force is to compare the total repository labor requirement with the size of the projected baseline work force. This number of direct workers is less than 1 percent of the estimated bicounty wage and salary employment (see Section 5.4.1.1). This comparison indicates that the available baseline work force would be adequate, although the mix of skills available may not adequately reflect project needs. However, baseline projections indicate that the region will contain significant numbers of workers with many of the skills required for a repository (Section 3.6.1).

Preliminary estimates of labor requirements indicate that at the peak of construction, the repository would increase regional construction employment by about 700 workers, which is approximately 3 percent of projected baseline bicounty construction employment in 1995 (Section 5.4.1.1). If vertical emplacement is used, mining employment (assumed to include mining support workers) would increase by about 40 percent over the projected Nye County baseline in 1995. Mining employment would decline to about 400 in 1998. This employment level would be maintained for about 20 years and represents approximately a 23 percent increase over mining employment projected for Nye County in the year 2000. While horizontal emplacement would require about 80 percent as many mining workers as vertical emplacement, the construction work force requirement would be about the same for both (Section 5.4.1.1). Thus, the development of a repository would place significant demands on the local mining sector and moderate demands on the local construction sector. Consequently, many mining and some construction workers would be drawn from outside the bicounty area. The extent of this inmigration would depend on the presence of other large projects in the early 1990s, the state of the national economy at that time, and the unemployment rates in those skill areas.

In summary, the total labor requirement of the repository appears small in comparison with the projected bicounty work force. However, although an adequate baseline work force would probably be available, it is likely that the available mining work force would be inadequate and it is possible that the construction work force could be also, although to a lesser degree. Thus the development of a repository at Yucca Mountain would lead to the inmigration of workers with these and other skills.

Conclusion

The work force in southern Nevada, including the Las Vegas Valley, is sufficiently large to site, construct, and operate a repository at Yucca Mountain. Although an adequate total work force may be available for a repository at Yucca Mountain, the available work force with mining skills would be inadequate and it is possible that the available construction work

force may also be inadequate. Therefore, the evidence indicates that this favorable condition is not present at Yucca Mountain.

(3) Projected net increases in employment and business sales, improved community services, and increased government revenues in the affected area.

Evaluation

Preliminary analyses summarized in sections 4.2.2.1.1 and 5.1.5 indicate that a maximum of about 700 direct and indirect jobs would be created in southern Nevada by site-characterization activities in the late 1980s, and a maximum of about 4,800 direct and indirect jobs would be created by the repository construction and operation in 1998. The potential annual wage-related increases in area income related to repository construction, operation, and decommissioning could reach $110 million in 1998 under vertical emplacement (Table 5-45). These and other direct and repository-induced expenditures would result in increased State and local government tax revenues, which may be offset by increased outlays.

This favorable condition requires increases in government revenues in the affected area, but it does not require a positive net fiscal balance. However, where State and local government outlays would exceed the revenue generated by the repository, the Federal Government would take action to provide financial assistance (Section 5.4.5). As a result, incremental State and local government outlays would not exceed incremental revenues and might actually be less. Additional data and analysis would be required to quantify the potential fiscal effects and appropriate levels of financial assistance.

In recent years, most community services in Clark and Nye counties have expanded to meet the needs of the area's rapidly growing population. Thus it is reasonable to expect that the community-services demand of repository-related workers and their dependents would result in an increase in these services, especially since local government revenues are expected to increase. It is also possible that the repository project could increase the quality of community services. For example, old facilities could be replaced by new facilities to serve a larger population, the increased population could support more diverse community services, and facilities could be acquired that would not otherwise be developed. Thus, the impact on the quality of community services would not necessarily be negative and could be positive.

In summary, preliminary analyses indicate that a repository at Yucca Mountain would result in projected net increases in employment and business sales and could result in improved community services and increased government revenues in the affected (i.e. bicounty) area. It is assumed that the DOE would work with State and local governmental entities to identify potential adverse fiscal effects requiring mitigation and that Federal financial and technical assistance would be provided, if necessary, to offset such potential effects. The fiscal effects include the increased spending by State and local entities responsible for providing community services.

Conclusion

A repository at Yucca Mountain would increase employment opportunities and business sales in southern Nevada. Community services could be improved, and government revenues are likely to increase. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(4) No projected substantial disruption of primary sectors of the economy of the affected area.

Evaluation

A <u>primary</u> or <u>basic sector</u> of the economy is one that produces goods sold outside the region. Interest in such sectors stems from the assumption that regional growth is intimately tied to the growth of primary sectors. Expansion of the primary sector is assumed to result in increased production by secondary, or support, sectors of the economy. Preliminary analyses indicate that in Clark and Nye counties, the important primary sectors are tourism and mining, respectively. Employment impacts of site characterization on these sectors are expected to be insignificant.

Even though repository-related increases in population may have a small positive effect on tourism, analyses to date have investigated only potential negative impacts. Preliminary results to date concerning the potential effect of repository operation on tourism are inconclusive (Section 5.4.1.6). However, preliminary analyses of cases examining the relationship of nuclear and non-nuclear safety concerns to tourism concluded that long term impacts on tourism were not apparent. Because of public concern about impacts on tourism, the importance of the tourism sector to the local and State economies, and the preliminary nature of the available data, this issue will be the subject of continued research.

Under vertical emplacement, repository mining employment would increase from a 1993 level of about 105 to a peak of about 630 in 1995 and 1996. This would represent nearly a 40 percent increase over projected Nye County baseline mining employment in 1995. Repository mining workers would be sustained at about 400 from 1998 to 2018. This number of workers would represent about a 23 percent increase over mining employment projected for Nye County in the year 2000 (see Section 5.4.1.1). Thus, the impact of the repository on mining employment is considered to favorably affect this primary sector of the economy. However, there may be secondary disruptive impacts due to worker relocation or increased labor costs.

Conclusion

The primary sectors of the economy in southern Nevada are tourism and mining. The employment impacts of site characterization on these sectors are expected to be insignificant. Information available to date does not suggest that the repository construction and operation would significantly affect tourism. Construction and operation of a repository would significantly increase employment in mining. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

6.2.1.7.4 Potentially adverse conditions

(1) Potential for significant repository-related impacts on community services, housing supply and demand, and the finances of State and local government agencies in the affected area.

Evaluation

In evaluating this potentially adverse condition, the U.S. Department of Energy (DOE) conducted a coarse screening so that detailed studies would not be undertaken for sites which ultimately would not be chosen for site characterization. Detailed quantitative information on current and projected levels of community services is not readily available. However, repository-related population growth rates are indirect indicators of the potential for community services and housing impacts. Qualitative information can also be used to evaluate service providers' potential capabilities to accommodate repository-related population growth. By limiting the analysis of this potentially adverse condition to estimated population growth rates with the repository, and qualitative information on community service providers, it was possible to use readily available information and avoid giving a false impression of precision, which could result from combining a more sophisticated analytical approach with insufficient data.

If service providers are unable to furnish, in a timely manner, the services and housing required by residents of the communities in which repository-related workers are expected to settle, impacts may be perceived by those residents. Generally, community services in the unincorporated towns nearest the repository site (i.e. Amargosa Valley, Beatty, Indian Springs, and Pahrump) are not provided by town governments. Instead, services are provided by the Nye and Clark county commissions, county-wide agencies (e.g. the Nye and Clark county school districts), local special purpose districts (e.g. the Beatty Water and Sanitation District), and voluntary organizations (e.g. Amargosa Volunteer Fire Department). With only a few exceptions, water in the unincorporated towns near the repository site is supplied by private wells and waste water is disposed in private septic tanks and leach fields (sections 3.6.3.3 and 3.6.3.4).

Housing in rural southern Nevada is provided almost entirely by the private sector. Ample land for expansion of housing is available in the rural towns closest to the repository site. In Indian Springs, for example, where most of the housing stock consists of mobile homes, the most recent land use plan for the community allows for approximately a fourfold increase in residential land use, much of it at higher densities than at present (Clark County Department of Comprehensive Planning, 1980).

Repository-related population increases during site characterization are not expected to significantly affect community services. The 1-year growth rate of the total population with the repository (i.e., baseline population plus estimated repository-related population) is used in this analysis of repository construction, operation and decommissioning. The total population growth rate is defined as the percentage change in the total population in 1-year relative to that in the previous year. These growth rates vary with changes in the number of direct workers (shown in tables 5-5a and 5-5b). In

the absence of detailed baseline community population forecasts, it was assumed that each community would retain its base year share of the county population shown in tables 3-15 and 3-16 (population values for years not shown in those tables were estimated by linear interpolation). Because of community population data availability, the base years for Clark and Nye county communities were 1980 and 1984, respectively (See Clark County Department of Comprehensive Planning, 1983; and Smith and Coogan, 1984). Indian Springs, in Clark County, was assumed to retain its 1980 share of the civilian population, and the number of military personnel were assumed to remain at the level estimated for 1980.

For purposes of this analysis, communities were grouped according to community ZIP code data reported by recent Nevada Test Site (NTS) workers and summarized in Table 5-26. Percentages reported in that table were used to estimate the size of the vertical emplacement repository-related maximum population increase (shown in Table 5-47) expected to settle in each community. This method is similar to that used in Section 4.2.2.2 to estimate the size of the maximum site-characterization-related population expected to settle in each community. The historical population used in that analysis, and shown in Table 4-5, is the base year population used in this analysis.

The maximum 1-year growth rate of the total community population with the repository (i.e., baseline population plus estimated repository-related population) was used as an indicator of the potential for impacts on community services, housing, and fiscal conditions, since these depend directly or indirectly on population. This maximum rate occurs between 1993 and 1994. Maximum 1-year community population growth rates have been estimated to be: 3.7 percent in unincorporated urban Clark County and Las Vegas, 3.9 percent in North Las Vegas, 13.2 percent in Indian Springs, 3.6 percent in Henderson, 3.3 percent in Boulder City, 5.0 percent in Pahrump, 4.1 percent in Tonopah, 2.4 percent in Beatty, and 2.5 percent in Amargosa Valley.

Growth rates estimated above for the urban areas of Clark County are generally within the range of those experienced historically (approximately 2.7 to 13.2 percent) by those urban communities (DOC, 1981) and their municipal service providers. Section 5.4.5 indicates that fiscal effects of community service impacts in these areas are expected to be observable, yet insignificant.

In Amargosa Valley and Beatty, town government consists of advisory councils. Indian Springs has a town advisory board and Pahrump has recently established a town board. Governmental organizations in these unincorporated towns have limited powers and resources related to community services. Although community-specific service and housing demands could increase at rates proportional to the maximum 1-year community population growth rates presented above, the potential impacts would be mainly on county-wide service providers that are more likely to have resources for managing growth.

Conclusion

Negative impacts on community services, housing supply and demand, and the finances of State and local government agencies in the affected area are

not expected to be significant for repository siting, construction, operation, and decommissioning. Although community-specific service and housing demands could increase at rates proportional to the maximum 1-year community population growth rates estimated with the repository, these rates are generally within the range of those experienced historically by the urban communities and their municipal service providers. Because the unincorporated towns nearest the Yucca Mountain site have limited powers dealing with community services, potential population growth in these communities would generally impact county-wide service providers. These service providers are more likely to have resources for managing growth. Additionally, the community level growth rates estimated for the unincorporated towns are generally within the range of those experienced historically by Nye and Clark counties (tables 3-15 and 3-16). Ample land is available for housing in the rural communities closest to the Yucca Mountain site. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(2) Lack of an adequate labor force in the affected area.

Evaluation

The availability of an adequate labor force in the affected area is discussed under favorable condition 2.

Conclusion

Although an adequate total work force would probably be available for a repository at Yucca Mountain, the available mining work force would be inadequate and it is possible that the construction work force could be also. Therefore, evidence indicates that this potentially adverse condition is present at Yucca Mountain.

(3) Need for repository-related purchase or acquisition of water rights, if such rights could have significant adverse impacts on the present or future development of the affected area.

Evaluation

According to preliminary analyses, the repository will require about 432,000 cubic meters (350 acre-feet) of water per year over a 32-year period which includes the construction period and the emplacement phase assuming vertical emplacement (Morales, 1985). This rate and quantity of withdrawal should not impinge on known water rights and should not affect other water users in the region (see favorable condition 2 in Section 6.3.1.1). The Alkali Flat-Furnace Creek Ranch ground-water basin in which Yucca Mountain is located contains no major developments or population centers that would compete with the repository for ground water. Analyses to date conclude that sufficient water to support the repository can be obtained from new or existing wells at the NTS (Section 6.3.3.3) for which the DOE has existing water rights.

Secondary effects on local water systems from the increased demand associated with population increases are expected to be minimal. Land-use restrictions through the granting of water permits by the Office of the State

Engineer of Nevada will also help to plan for and to minimize effects on local aquifers. Some communities may require financial or technical assistance to expand their water delivery systems to meet demands of repository related population growth. The Las Vegas valley is projected to have water-supply problems by the year 2020, even without the population increases resulting from development of the repository (Section 5.4.3.3). Local officials are evaluating alternatives to alleviate this problem.

Conclusion

Preliminary analyses of water supply and demand indicate repository-related water use will not have significant adverse impacts on present or future development in the region surrounding Yucca Mountain. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(4) Potential for major disruptions of primary sectors of the economy of the affected area.

Evaluation

The absence of any projected substantial disruption of the primary sectors of the economy of the affected area is discussed under favorable condition 4.

Conclusion

The primary sectors of the economy in southern Nevada are tourism and mining. Information available to date does not suggest that the repository is likely to have significant effects on tourism. It would increase employment in construction and significantly increase employment in mining. This increase is not considered to be a major disruption. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

6.2.1.7.5 Disqualifying condition

A site shall be disqualified if repository construction, operation, or closure would significantly degrade the quality, or significantly reduce the quantity, of water from major sources of offsite supplies presently suitable for human consumption or crop irrigation and such impacts cannot be compensated for, or mitigated by, reasonable measures.

Evaluation

Repository construction, operation, and closure would increase water consumption through water use at the repository and the use of water by the inmigrating population. The effects of this water use are described in sections 5.2.2 and 5.4.3. Because the climate is arid and the water table is deep (more than 200 meters (656 feet) below the repository horizon), it is

extremely unlikely that repository activities could degrade the quality of ground water in the Yucca Mountain region.

Ground water would be the repository water source (see Section 5.1), and competing requirements for ground-water use have been considered. Surface water has not been considered for repository or domestic use, because it is not generally available in this arid region. Well J-13 and the proposed locations of repository surface facilities are on the Nevada Test Site. If a repository is developed at Yucca Mountain, a permanent land withdrawal will be necessary, in accordance with the Federal Land Policy and Management Act of 1976. Reservation of water rights is explicit in the withdrawal, as described in the guideline on site ownership and control (Section 6.2.1.3). The Office of the State Engineer of Nevada has prepared a series of water planning reports, and the second report of the series includes estimates of water withdrawals and consumption by counties and hydrographic regions (Office of the State Engineer, 1971). These estimates provided a basis for projecting future water requirements in Nevada. Estimates of water require- ments for the construction, operation, decommissioning, and closure of the repository are based on preliminary conceptual designs. For the first 32 years of repository construction and operation, it is estimated that an average of about 432,000 cubic meters (350 acre-feet) per year of water will be used (Morales, 1985).

The regional effects of withdrawing ground water for a repository at Yucca Mountain are expected to be negligible. Thordarson (1983) reports that the water level in Well J-13 has remained essentially constant after long periods of pumping between 1962 and 1980. The large volume of water produced from this well, along with the evidence of only minor drawdown during pumping tests, suggests that the aquifers underlying Yucca Mountain can yield large quantities of ground water for long periods of time without lowering the regional ground-water table.

Municipal water-supply systems for Nye County and Clark County com- munities are detailed in Section 3.6.3.3. At present, the size of municipal and private utility systems in most communities near Yucca Mountain appears adequate for current population levels. Several communities have plans for improvements that will require a number of years to complete, such as new wells and water distribution and sewer lines. These plans were designed to accommodate projected baseline growth in the immediate vicinity of the communities. The major problem presently associated with the expansion of water systems is identifying additional potable-water sources and obtaining adequate development capital.

According to an investigation sponsored by the State of Nevada (State of Nevada, NDCNR, 1982), there are both legal and technical uncertainties as to the ability of existing sources to meet the water-supply needs of the Las Vegas valley beyond the year 2020, or when the population reaches about 1 million people, if present rates of water use continue. The increase in water demand due to repository-related population growth may slightly accelerate the time when present sources become inadequate. The analyses in Section 5.4.2 and in favorable condition 1 in this section, indicate that a maximum 1-year population growth rate of about 3.7 percent is expected for Clark County and 4.0 percent is expected for Nye County with the repository. These population growth rates associated with the repository are within the

range of those experienced historically in the bicounty area, and are not
likely to significantly aggravate the water-supply situation.

Conclusion

The projected population increases associated with the repository con-
struction and operation are relatively small. However, proper planning is
needed to ensure that the expansion of water supplies occurs in a timely
manner. The Nuclear Waste Policy Act (NWPA, 1983) provides for finanical and
technical assistance, which could enable local communities to prepare for
increased growth. Repository construction, operation, or closure would not
significantly degrade the quality, nor would water use associated with the
repository significantly reduce the quantity of water from major sources of
offsite supplies presently suitable for human consumption or crop irrigation.
Therefore, the evidence does not support a finding that the site is
disqualified (level 1).

6.2.1.7.6 Evaluation and conclusion for the qualifying condition on the socioeconomic impacts guideline

Evaluation

An analysis of the adverse impacts of locating a repository at Yucca
Mountain must consider the following areas: significant adverse impacts on
labor; on the primary or basic sectors of the economy; on direct and indirect
employment and business sales; on competition for water resources; on com-
munity services; on housing supply and demand; and on public-agency revenues
and expenditures. It is assumed that the U.S. Department of Energy (DOE)
will take reasonable mitigative or compensatory action under the provisions
of the Nuclear Waste Policy Act (the Act) of 1982, if it is needed in these
areas (NWPA, 1983).

As discussed in Section 5.4, preliminary analyses of labor demand,
materials and resources, income, and land use reveal no potentially signi-
ficant adverse impacts. It is expected that impacts on State and local com-
munity infrastructure discussed in Section 5.4 can be offset by reasonable
mitigation or compensation under the financial and technical assistance pro-
visions of the Nuclear Waste Policy Act (NWPA, 1983). The DOE maintains a
commitment to consult and cooperate with responsible State and local govern-
ments in identifying specific areas where adverse impacts could occur and in
developing appropriate measures of corrective action and mitigation (includ-
ing mitigation by avoidance). Ongoing research and analysis of potential
impacts on tourism will further assess the potential for adverse effects of a
repository at Yucca Mountain. Further research will examine the potential
for impacts on social structure and organization including social problems,
culture and lifestyle, and on overall quality of life. No unmitigable sig-
nificant adverse impacts have been identified in any of these areas.

A summary of the evaluation to date of the socioeconomic impacts of
repository siting, construction, and operation, is given in chapters 4 and 5.
Future socioeconomic evaluations that are discussed below will be undertaken
if the Yucca Mountain site is approved for site characterization. The DOE

will establish a monitoring program to validate the expected socioeconomic impacts of site characterization presented in Chapter 4, and identify mechanisms by which the DOE would determine appropriate and timely corrective action for any unexpected significant adverse social and economic impacts that are identified by that monitoring program. More detailed studies regarding baseline socioeconomic conditions identified in Chapter 3, and the effects of repository construction, operation, decommissioning, and closure presented in Chapter 5 will be undertaken in preparation of an environmental impact statement. If the Yucca Mountain site is selected for development of a repository, plans to monitor repository activities and mitigate socioeconomic impacts would be developed in consultation with State and local governmental representatives. As more specific system-design information becomes available or as impact issues are raised, other means of protecting the socioeconomic welfare--the aggregate well-being of area residents--of the general public in the affected area will be identified.

Conclusion

The siting, construction, operation, decommissioning, and closure of a repository at Yucca Mountain are not expected to generate any significant adverse socioeconomic effects on the surrounding region that cannot be offset by reasonable mitigation or compensation through a process of planning, analysis, and consultation among the DOE, the affected State, and local governmental jurisidictions. This assessment is based on preliminary design and impact studies. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for socioeconomic impacts (level 3).

6.2.1.8 Transportation (10 CFR 960.5-2-7)

6.2.1.8.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall be located such that (1) the access routes constructed from existing local highways and railroads to the site (i) will not conflict irreconcilably with the previously designated use of any resource listed in 960.5-2-5(d)(2) and (3); (ii) can be designed and constructed using reasonably available technology; (iii) will not require transportation system components to meet performance standards more stringent than those specified in the applicable DOT and NRC regulations, nor require the development of new packaging containment technology; (iv) will allow transportation operations to be conducted without causing an unacceptable risk to the public or unacceptable environmental impacts, taking into account programmatic, technical, social, economic, and environmental factors; and (2) the requirements of Section 960.5-1(a)(2) can be met.

The objective of the preclosure transportation technical guideline is to ensure that proper consideration is given to the transportation of waste to a

repository site, as it could affect the health and safety of the public, the environment, and the cost of waste disposal. Areas of concern include (1) the construction of access routes from existing local highways and railroads to the site; (2) the improvement and use of existing local highway and railroad networks; (3) projected risks, costs, and other impacts of waste transportation; and (4) compliance with applicable Federal, State, and local regulations.

The guideline contains nine favorable conditions, four potentially adverse conditions, and one qualifying condition. A summary of the evaluations that follow is given in Table 6-12.

6.2.1.8.2 Data relevant to the evaluation

Preliminary design drawings and cost estimates have been used as the basis for evaluating proposed access routes to the Yucca Mountain site from existing regional highways and mainline railroads. A Bureau of Land Management wilderness status map (BLM, 1983) was used to assess the location of these routes in relation to land ownership and resource areas addressed in Section 6.2.1.6, disqualifying conditions 2 and 3.

Atlases published by the Nevada Department of Transportation and Rand McNally were used to calculate distances from the site to regional highways and mainline railroads. Information on railroad interchange points was provided by the Union Pacific Railroad (Nunn, 1983). The costs and risks of transporting radioactive wastes to potential first repository sites in the United States, including Yucca Mountain, are estimated in Appendix A (Transportation).

The statutes and regulations of Nevada and adjoining states were obtained from the legislative data base at the Oak Ridge National Laboratory and from a report issued by the National Conference of State Legislatures (Foster, 1983). They were compared with U.S. Department of Transportation regulations in 49 CFR Part 177 (1983), with 10 CFR 71.5a (1984), and with 10 CFR 73.37 (1984).

Information on emergency response to accidents during radioactive-waste transport in the State of Nevada was obtained from the State of Nevada's Radiological Emergency Response Plan (State of Nevada, Department of Human Resources, 1983) and the U.S. Department of Energy, Nevada Operations Office (DOE/NVO, 1985). Information on regional weather conditions was obtained from publications by the U.S. Department of Commerce (DOC, 1952, 1968), Lineham (1957), Thom (1963), Pautz (1969), Bowen and Egami (1983), Hershfield (1961), and Quiring (1983). Information regarding road closures was obtained from Hill (1985a,b).

The data and methods used to estimate the radiological impacts are described in Appendix A (Transportation). The appendix also describes the computer program used to calculate the impacts and the routing models used to postulate highway and rail travel routes and distances.

Table 6-12. Summary of analyses for Section 6.2.1.8; transportation (10 CFR 960.5-2-7)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITIONS	
(1) Present highway or access routes from local existing highways and railroads to the site which have any of the following characteristics.	The evidence indicates that this favorable condition is present at Yucca Mountain: the Yucca Mountain site meets three out of five characteristics; only one is required.
(i) Such routes are relatively short and economical to construct as compared to access routes for other comparable siting options.	Routes will not be relatively short and economical to construct.
(ii) Federal condemnation is not required to acquire rights-of-way for the access routes.	Federal condemnation will not be necessary.
(iii) Cuts, fills, tunnels, or bridges are not required.	Minor cuts and fills and a bridge are required along the access route.
(iv) Such routes are free of sharp curves or steep grades and are not likely to be affected by landslides or rock-slides.	No sharp turns or steep grades are required; routes will avoid areas likely to be affected by landslides or rockslides.
(v) Such routes bypass local cities and towns.	Access routes will bypass cities and towns.
(2) Proximity to local highways and railroads that provide access to regional highways and rail-roads and are adequate to serve the repository without significant upgrading or reconstruction.	The evidence indicates that this favorable condition is present at Yucca Mountain: the local transportation infrastructure will not require upgrading or reconstruction.

Table 6-12. Summary of analyses for Section 6.2.1.8; transportation (10 CFR 960.5-2-7) (continued)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITIONS (continued)	
(3) Proximity of regional highways, mainline railroads, and inland waterways that provide access to the national transportation system.	The evidence indicates that this favorable condition is present at Yucca Mountain: an access road provides direct access to the regional system, and a railspur provides direct access to the mainline railroad.
(4) Availability of a regional railroad system with a minimum number of interchange points at which train crew and equipment changes would be required.	The evidence indicates that this favorable condition is present at Yucca Mountain: a minimum number of interchange points exists for crew and equipment changes.
(5) Total projected life-cycle cost and risk for the transportation of all wastes designated for the repository which are significantly lower than those for comparable siting options, considering locations of present and potential sources of waste, interim storage facilities, and other repositories.	The evidence indicates that this favorable condition is not present: cost and risk are not significantly lower than those for comparable siting options.
(5) Availability of regional and local carriers—truck, rail, and water—which have the capability and are willing to handle waste shipments to the repository.	The evidence indicates that this favorable condition is present at Yucca Mountain: the Union Pacific Railroad is a regional carrier, local carriers will have the capability of supporting construction-related activities, and national or multiregional carriers will be deployed for waste shipments.

Table 6-12. Summary of analyses for Section 6.2.1.8; transportation (10 CFR 960.5-2-7) (continued)

Condition	Department of Energy (DOE) finding

FAVORABLE CONDITIONS (continued)

(7) Absence of legal impediment with regard to compliance with Federal regulations for the transportation of waste in or through the affected State and adjoining States.

The evidence indicates that this favorable condition is present at Yucca Mountain: existing State and local regulations considered to be impediments are preempted by Federal regulations, unless allowed to stand by the U.S. Department of Transportation, or the Federal judicial system.

(8) Plans, procedures, and capabilities for response to radioactive-waste transportation accidents in or through the affected State that are completed or being developed.

The evidence indicates that this favorable condition is present at Yucca Mountain: the State of Nevada and the DOE have plans, procedures, and capabilities for responding to accidents from transporting radio-active wastes.

(9) A regional meteorological history indicating that significant transportation disruptions would not be routine seasonal occurrences.

The evidence indicates that this favorable condition is present at Yucca Mountain: southern Nevada has one of the lowest frequencies of occurrence of severe weather in the United States, and significant transportation disruptions due to routine or sea-sonal severe weather conditions are not expected.

POTENTIALLY ADVERSE CONDITIONS

(1) Access routes to existing local highways and railroads that are expensive to construct relative to comparable siting options.

The evidence indicates that this potentially adverse condition is present at Yucca Mountain: the length of the railroad spur and the bridge over Fortymile Wash cause the construction cost to be high rela-tive to comparable siting options.

Table 6-12. Summary of analyses for Section 6.2.1.8; transportation (10 CFR 960.5-2-7) (continued)

Condition	Department of Energy (DOE) finding
POTENTIALLY ADVERSE CONDITIONS (continued)	
(2) Terrain between the site and existing local highways and railroads such that steep grades, sharp switchbacks, rivers, lakes, landslides, rockslides, or potential sources of hazard to incoming waste shipments will be encountered along access roads to the site.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: the terrain slopes gently on road and rail access so that no sharp curves or steep grades are required; no hazards to waste shipments have been identified. No surface water is present between the site and existing highways and railroads and areas of expected landslides or rockslides will be avoided.
(3) Existing local highways and railroads that could require significant reconstruction or upgrading to provide adequate routes to the regional and national transportation system.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: the railspur will provide direct access to the national railroad system; the access road will link the site to U.S. Highway 95, a regional highway, therefore no upgrading of local highways and railroads will be required.
(4) Any local condition that could cause the transportation-related costs, environmental impacts, or risk to public health and safety from waste transportation operations to be significantly greater than those projected for other comparable siting options.	The evidence does not support the conclusion that this potentially adverse condition is not present at Yucca Mountain: as presently configured the pro- posed rail spur will pass close to a U.S. Air Force bombing range which could possibly increase the risk compared to other siting options. Consequently, this potentially adverse condition is present at Yucca Mountain.

Table 6-12. Summary of analyses for Section 6.2.1.8; transportation (10 CFR 960.5-2-7) (continued)

Condition	Department of Energy (DOE) finding
QUALIFYING CONDITION The site shall be located such that (1) the access routes constructed from existing local highways and railroads to the site (1) will not conflict irreconcilably with the previously designated use of any resource listed in 960.5-2-5(d)(2) and (3); (ii) can be designed and constructed using reasonably available technology; (iii) will not require transportation system components to meet performance standards more stringent than those specified in the applicable DOT and NRC regulations, nor require the development of new packaging containment technology; (iv) will allow transportation operations to be conducted without causing an unacceptable risk to the public or unacceptable environmental impacts; taking into account programmatic, technical, social, economic, and environmental factors; and (2) the requirements of Section 960.5-1(a)(2) can be met.	Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): Yucca Mountain has adequate year-round access to transportation routes whose use will not conflict irreconcilably with the previously designated land use or land dedication to resource preservation; all routes can be constructed with reasonably available technology without excessive cost; transportation-system components will not be required to meet standards greater than applicable DOT and NRC regulations; no unacceptable environmental radiological or nonradiological risk to the public or environment from transportation operations is expected.

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Assumptions, data uncertainties, and consistency

In order to ensure that all sites were evaluated in a consistent manner, a common set of criteria were developed by the U.S. Department of Energy (DOE). Where possible, the criteria were quantified (Appendix A). These criteria will be identified as required in the following sections to explain the positions taken

Information on the costs and risk of transporting wastes to the Yucca Mountain site along highways and rail lines must be regarded as best estimates only in view of the preliminary nature of the transportation studies.

6.2.1.8.3 Favorable conditions

(1) Availability of access routes from local existing highways and railroads to the site which have any of the following characteristics:

(i) Such routes are relatively short and economical to construct as compared to access routes for other comparable siting options.

Evaluation

Highway access to the Yucca Mountain site would originate at U.S. Highway 95 approximately 1 kilometer (0.5 mile) west of the Town of Amargosa Valley and extend about 25 kilometers (16 miles) northward to the site. The proposed rail line would originate from the Union Pacific line at Dike Siding, 18 kilometers (11 miles) northeast of downtown Las Vegas, and would extend approximately 161 kilometers (100 miles) to the site. Access road costs are estimated at $12.5 million (1984 dollars). Rail and bridge costs are estimated at $151 million (1984 dollars). For the purpose of interpreting this favorable condition, the DOE established criteria of 16 kilometers (10 miles) and $10 million as relatively short and economical.

Conclusion

Yucca Mountain does not possess this characteristic of the favorable condition.

(ii) Federal condemnation is not required to acquire rights-of-way for the access routes.

Evaluation

Except for Dike Siding, the proposed rail access route and the access road are located exclusively on Federal lands administered by the DOE, the U.S. Department of the Air Force, and public-domain lands under the jurisdiction of the Bureau of Land Management (sections 6.2.1.1 and 6.2.1.3).

Conclusion

Since neither the proposed rail nor road access routes cross any private land, Federal condemnation will not be required. Therefore this favorable characteristic is present at Yucca Mountain.

(iii) Cuts, fills, tunnels, or bridges are not required.

Evaluation

The terrain along the route for both road and rail is gently sloping. Preliminary design estimates indicate that no tunnels and only a minimum amount of excavation would be required. Some minor drainage structures and a new bridge spanning Fortymile Wash would be constructed. The construction of this bridge presents no engineering or construction difficulties.

Conclusion

The only significant surface feature to be encountered is Fortymile Wash. Because a bridge over Fortymile Wash would have to be built, the evidence indicates that this favorable characteristic is not present at Yucca Mountain.

(iv) Such routes are free of sharp curves or steep grades and are not likely to be affected by landslides or rockslides.

Evaluation

The railbed will be designed for maximum grades of 1 to 3 percent. Curves will be limited to approximately 2 degrees. The roadbed will be designed for a maximum grade of 3 percent and will be free of sharp curves. Landslides or rockslides along the rail and highway access routes are unlikely because the routes will be chosen to avoid locations with the potential for such events.

Conclusion

The terrain for the proposed rail and road access routes is gently sloping, no sharp curves are required, and no difficult design or engineering problems in ensuring surface stability are expected. Therefore, the evidence indicates that this favorable characteristic is present at Yucca Mountain.

(v) Such routes bypass local cities and towns.

Evaluation

According to preliminary design drawings, the proposed rail spur will bypass the towns of Cactus Springs and Indian Springs, as well as the facilities at Indian Springs Air Force Base. The rail line will originate 18 kilometers (11 miles) northeast of downtown Las Vegas. The proposed access road to the site will intersect U.S. Highway 95 approximately 1 kilometer (0.5 mile) west of the town of Amargosa Valley. For purposes of evaluating sites on the basis of this guideline, the DOE criteria for local cities and towns are the population values established in 10 CFR 960.5-2-1(c)2

(1984) at 1,000 people per square mile and the associated 10 CFR 960.2 (1984), which defines a highly populated area as any place of 2,500 or more persons. No population centers greater than the given DOE criteria are located along these proposed routes.

Conclusion

Information indicates that the rail and highway access routes to the Yucca Mountain site will bypass local cities and towns; furthermore no population centers (as defined above) exist along the access routes. Therefore, the evidence indicates that this favorable characteristic is present at Yucca Mountain.

Summary conclusion for favorable condition 1

Favorable condition 1 is present at Yucca Mountain. To have this favorable condition, only one of the characteristics need be present. As shown in the above discussions, three of the favorable characteristics are present for the Yucca Mountain site.

(2) **Proximity to local highways and railroads that provide access to regional highways and railroads and are adequate to serve the repository without significant upgrading or reconstruction.**

Evaluation

This favorable condition applies to local roads and rail lines from the outer end of the access routes to a point where upgrading is no longer required.

The new access road to be constructed southward from the site will provide direct access to U.S. Highway 95, a regional highway, and no local highways will be used for the repository. The railroad spur from Yucca Mountain to Dike Siding, 18 kilometers (11 miles) northeast of Las Vegas, will connect directly to the national rail network.

Conclusion

No upgrading or reconstruction of local highways or rail lines is required. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(3) **Proximity to regional highways, mainline railroads, or inland waterways that provide access to the national transportation system.**

Evaluation

This favorable condition applies to the distance between the outer end of the access routes and the closest regional highway and mainline railroad that would be used.

The access road to be constructed southward from the Yucca Mountain site will provide direct access to U.S. Highway 95, a regional highway providing

access to Interstate 15, Interstate 40, and Interstate 80, all of which are part of the national transportation system. The proposed rail spur will connect directly to the main Union Pacific line. This is a class A main line, which among other things means that it is part of the Strategic Rail Corridor Network and therefore is part of the national network.

Conclusion

The proposed highway and rail access routes constructed from the Yucca Mountain site will hook up directly to the regional and national transportation systems, respectively. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(4) Availability of a regional railroad system with a minimum number of interchange points at which train crew and equipment changes would be required.

Evaluation of equipment changes

According to an official of the Union Pacific Railroad (Nunn, 1983) the Union Pacific could interchange at Ogden, Utah, with the Southern Pacific Railroad. This may not be required, however, because of the areas served directly by Union Pacific: (1) San Francisco, California, which is served by the recently acquired Western Pacific line; (2) the eastern United States as far east as St. Louis, Missouri, Chicago, Illinois, and Memphis, Tennessee; (3) the Pacific Northwest; and (4) the Gulf ports in Texas and Louisiana. Locomotives almost always go straight through from Salt Lake City to at least Yermo, California (both of which are transfer points), and often on to Los Angeles.

Evaluation of crew changes

Crew-change locations along the Union Pacific line between Salt Lake City and Los Angeles are Salt Lake City and Milford, Utah; Las Vegas, Nevada; and Yermo and Los Angeles, California. The vast majority and possibly all waste destined for Yucca Mountain by rail will travel southbound and be diverted to the spur at Dike Siding before reaching Las Vegas. Therefore the only railroad crew change would be for waste being shipped in general commerce heading northbound from southern California.

The DOE criterion for this favorable condition is the number of interchange points within 200 kilometers (125 miles) of the site. Las Vegas is the only one that will become an interchange point for waste (if any) that is being shipped in general commerce from California.

Conclusion

The regional railroad system has one interchange point within 200 kilometers (125 miles) of the site, which is the minimum number of interchange points. Data for comparison with other siting options can be found in Chapter 7. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(5) Total projected life-cycle cost and risk for transportation of
all wastes designated for the repository site which are signifi-
cantly lower then those for comparable siting options, considering
locations of present and potential sources of waste, interim
storage facilities, and other repositories.

Evaluation

Projected life-cycle cost and risk for the transportation of all wastes
designated for the potential repository at Yucca Mountain are presented in
Section 5.3 and Appendix A. The data for cost and risk for comparable siting
options can be found in Chapter 7. The long distance involved in travel from
the east produce relatively high shipping cost and risk for the Yucca
Mountain site.

Conclusion

As cost and risk are strongly influenced by distance, the evidence
suggests that this favorable condition is not present for Yucca Mountain.

(6) Availability of regional and local carriers—truck, rail, and
water—which have the capability and are willing to handle waste
shipments to the repository.

Evaluation

The analysis in Section 5.3 indicates that the Union Pacific Railroad
has the capacity to carry the shipments associated with waste transport.
Waste transport by truck will be contracted for on a national or multi-
regional basis, thereby taking the burden off of local carriers.

Conclusion

The Union Pacific meets the qualifications of a regional carrier having
the capacity to handle waste shipments as noted in Section 5.3. Therefore,
the evidence indicates that this favorable condition is present at Yucca
Mountain.

(7) Absence of legal impediment with regard to compliance with
Federal regulations for the transportation of waste in or through
the affected State and adjoining States.

Evaluation

A legal impediment could only exist if State, local, or tribal law
rendered compliance with U.S. Department of Transportation (DOT) regulations
impossible, without being found to be preempted by the Federal judicial
system. California time-of-day requirements and the banning of radioactive
waste shipments in Humboldt and Marin counties as well as the recently passed
Las Vegas, Nevada, ordinance (No. 3190), are the only regulations considered
impediments to waste shipments. However, these regulations are considered
preempted by DOT regulations until they are allowed to stand by either DOT or
the Federal judicial system.

Conclusion

There are no legal impediments that are not considered to be preempted by DOT regulations. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(8) Plans, procedures, and capabilities for response to radioactive waste transportation accidents in the affected State that are completed or being developed.

Evaluation

The State of Nevada Radiological Emergency Response Plan (State of Nevada, Department of Human Resources, 1983) identifies the agencies and individuals to be notified in the event of a radiological emergency, provides guidance for plan participants, and establishes procedures for requesting and providing assistance.

Through an agreement with Region 7 of the DOE, and in accordance with the Memorandum of Understanding on responses to hazardous materials accidents, the DOE Nevada Operations Office (DOE/NVO) is the primary contact for coordination of the initial response to a radiological emergency in the State of Nevada. Telephone calls are answered by the 24-hour guard station at the main DOE office building in Las Vegas. Cards containing this number have been distributed by the Nevada State Division of Emergency Management to State, county, and city authorities. Duty officers assigned on a rotating schedule ensure immediate 24-hour contact with the DOE guard station using a beeper and can be immediately mobilized when needed. Notification procedures of the Radiological Assistance Team are published by the DOE/NVO (1985). In southern Nevada, a Radiological Assistance Team with a specially equipped vehicle is also available. In northern Nevada, the State Emergency Response Team, composed of State and university personnel, is responsible for emergency response.

The capability of the DOE for responding to radiological emergencies is well developed in terms of trained personnel, equipment, and facilities. Professional personnel—including health physicists, medical specialists, physical and biological scientists, and technical personnel such as radiation monitors, instrumentation specialists, and radioactive-material handlers—are included in the Radiological Assistance Team. In addition, the team is accompanied by a trained public-affairs person. Equipment is available for personnel protection, transportation, communications, and radiation monitoring; facilities are also available for biological assays, chemical analyses, and decontamination. Regional capability includes, in addition to the Radiological Response Cleanup Team, an Aerial Measurements Systems Group that has the ability to rapidly assess very large land areas.

First-on-scene training courses have been developed and conducted for ambulance operators and Nevada State law-enforcement personnel. Civil defense radiation-monitoring kits have been given to each State highway patrolman and selected municipal and county officers who complete the training course. The kits are maintained regularly.

The DOE criterion for this favorable condition is that evidence exists that there are plans, procedures, and capabilities.

Conclusion

The State of Nevada in cooperation with the DOE Nevada Operations Office has completed plans, procedures, and capabilities for responding to accidents during the transportation of radioactive materials. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(9) A regional meteorological history indicating that significant transportation disruptions would not be routine seasonal occurrences.

Evaluation

Recorded occurrences of severe weather in Nevada include thunderstorms, snowstorms, tornadoes, hail, and sandstorms, but the frequencies of most events are very low. Thunderstorms have been observed on the average of 14 days per year at Yucca Flat (Bowen and Egami, 1983), 11 days per year at Winnemucca to the north, 14 days per year at Reno to the northwest, and 31 days per year at Ely, to the northwest (DOC, 1952). Approximately 60 to 70 percent of these thunderstorms occur during the summer season. Tornadoes are very rare in Nevada, with the probability of a tornado striking Yucca Mountain conservatively estimated to be 7.5×10^{-4} per year, or once in 1,333 years (Thom, 1963). Occurrences of tornadoes elsewhere in the State are equally rare, and no tornado-related deaths have been reported for Nevada for the record period from 1916 to 1953 (Lineham, 1957). Hail with a diameter of 1.9 centimeters (0.75 inch) or larger was observed on 7 days in Nevada between 1955 and 1967 (Pautz, 1969). Sandstorms are common in Nevada, but they are rarely severe enough to affect transportation. The greatest 24-hour snowfall measured at Yucca Flat was 21 centimeters (8.3 inches) (Bowen and Egami, 1983). Annual total snowfalls of up to 150 centimeters (60 inches) have been observed at some of the higher elevations in the State (DOC, 1968), but these areas are not likely to be traversed by waste-transportation carriers. The annual precipitation in Nevada is generally low, with the northern half of the State receiving more precipitation than the arid southern region.

Although it is not strictly a weather condition, but rather the result of regional sporadic weather conditions, the possibility of flash flooding will be taken into account in the design of access routes. Beatty rainfall patterns should be indicative of the southwestern Nevada Test Site. A 24-hour precipitation event of more than 51 millimeters (2.0 inches) has a recurrence period of 25 years for Beatty (Bowen and Egami, 1983). At Yucca Flat, the statistical maximum 24-hour precipitation for 10- and 100-year storm events is 38 and 57 millimeters (1.50 and 2.25 inches), respectively (Hershfield, 1961). Quiring (1983) updated the 10- and 100- year storm event precipitation data for Yucca Flat to 45 and 68 millimeters (1.8 and 2.7 inches) respectively. Flash floods resulting from this intense rainfall are generally of short duration, and standard drainage-control measures should reduce risks to acceptable levels.

The above data suggest that significant transportation disruptions due to weather are rare in Nevada. This is supported by road-closure information obtained from Hill (1985a,b), which states that

1.   During 1984 there were three total closures of Interstate 15 and no total closures of Interstate 80 due to weather conditions.

2.   Over the past year U.S. Highway 95 between Interstate 15 and Interstate 80 was closed three times because of weather.

3.   All total closures were due to flooding.

The DOE criterion defines significant disruptions as those that could cause the repository not to meet its annual receipt rate.

Conclusion

Southern Nevada has one of the lowest frequencies of occurrence of severe weather in the United States. Road-closure information suggests that transportation disruptions would not be routine seasonal occurrences and would not adversely affect the ability of the repository to meet its annual receipt rate. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

6.2.1.8.4   Potentially adverse conditions

(1)   <u>Access routes to existing local highways and railroads that are expensive to construct relative to comparable siting options.</u>

Evaluation

Details of access routes for the Yucca Mountain site are presented in the evaluation of favorable condition 1(i). As with favorable condition 1(i), the U.S. Department of Energy (DOE) criterion for expensive construction was set equal to or greater than $10 million.

Conclusion

According to the DOE criterion, Yucca Mountain possesses this potentially adverse condition.

(2)   <u>Terrain between the site and existing local highways and railroads such that steep grades, sharp switchbacks, rivers, lakes, landslides, rock slides, or potential sources of hazard to incoming waste shipments will be encountered along access roads to the site.</u>

Evaluation

The terrain along the road and rail access routes is gently sloping, and steep grades, sharp switchbacks, rivers, lakes, landslides, rock slides, or other potential sources of hazard to incoming waste shipments will not be encountered along access routes to the proposed site (see favorable conditions 1(iii) and (iv)).

Conclusion

The access road and rail spur will be built over terrain that presents no potential hazards to incoming waste shipments. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

> (3) Existing local highways and railroads that could require significant reconstruction or upgrading to provide adequate routes to the regional and national transportation system.

Evaluation

The proposed rail spur from the site to Dike Siding will provide direct access to the national railroad system. Hence, there will be no upgrading or reconstruction of existing local networks. The access road will provide access directly to the regional network (U.S. Highway 95). Consequently, no upgrading of local roads will be required (see favorable condition 2).

Conclusion

There are no local highways and railroads connecting the Yucca Mountain site to the regional or national transportation system. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

> (4) Any local condition that could cause the transportation-related costs, environmental impacts, or risk to public health and safety from waste transportation operations to be significantly greater than those projected for other comparable siting options.

Evaluation

Risk to public health and safety from transportation operations for comparable siting options is addressed in Chapter 7 and in Appendix A. These conditions are evaluated for only the Yucca Mountain site. The population density in the area covered by access routes to the potential Yucca Mountain site for rail and highway is very low, as discussed in the preclosure system guideline for radiological safety (Section 6.2.2.1). There are no permanent residents within 10 kilometers (6.2 miles) of the site. The costs are not expected to be unreasonable for constructing either route, because the terrain is generally flat or gently sloping, no tunnels need to be excavated, and only one bridge is required. No specialized technology is required for constructing the rail line or highway. Much of the land is already controlled by the Federal Government. Environmental impacts from access road and rail construction and use are expected to be minimal. However, the rail spur as currently envisioned will pass close to a U.S. Air Force (USAF) bombing ranges in the vicinity of Indian Springs. Although there is no evidence to suggest that this presents a significantly greater risk than other comparable siting options, a detailed study will be conducted during site characterization to examine the potential risk associated with the relative location of the proposed rail spur and military activities in the area.

Conclusion

Since the risk associated with the proximity of the rail spur to the USAF bombing range has yet to be quantified, it cannot be concluded that Yucca Mountain does not possess this potentially adverse condition. Consequently, the evidence indicates that this potentially adverse condition is present at Yucca Mountain.

6.2.1.8.5 Evaluation and conclusion for the qualifying condition on the transportation guideline

Evaluation

Except for Dike Siding, all the rail and highway access routes for the Yucca Mountain site are located on government controlled lands, and no Federal condemnation proceedings are expected. Access routes constructed from existing highways and railroads will not conflict irreconcilably with the previously designated use of any environmental resource listed in Section 6.2.1.6 (Environmental quality). These routes can be constructed with reasonably available technology. Transportation-system components can be designed to meet applicable Department of Transportation and Nuclear Regulatory Commission regulations.

Construction costs for access routes, although high compared with other sites, should not be unreasonable, because the terrain is generally flat or gently sloping, no tunnels would need to be excavated, and only one bridge would be required. The existing roads and railroads provide ready access to the regional transportation system without requiring upgrading of local roads. Also, the Union Pacific Railroad serves many distant points, minimizing the need for equipment and crew changes. Because southern Nevada has one of the lowest frequencies of severe weather in the United States, transportation would not be adversely affected by weather conditions.

The public and the environment can be adequately protected from any potential hazards posed by the transportation of radioactive wastes (Section 6.2.2.2). No local conditions have been identified that would make the risk to public health and safety unacceptable. The State of Nevada in cooperation with the U.S. Department of Energy (DOE) has completed plans and procedures for responding to accidents involving radioactive materials. The DOE Nevada Operations Office coordinates the response to radiological emergencies.

Conclusion

The Yucca Mountain site has adequate access to existing transportation routes, and new access routes can be constructed with reasonably available technology and at reasonable cost. Transportation operations can be conducted without causing unacceptable radiological or nonradiological risk to the public or unacceptable environmental impacts. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for transportation (level 3).

The purpose of the preclosure system guidelines is to establish the overall objectives to be met by a repository during the preclosure phase (i.e., siting, construction, and operation through closure). There are three preclosure system guidelines: (1) preclosure radiological safety; (2) environment, socioeconomics, and transportation; and (3) ease and cost of siting, construction, operation, and closure. The first two are discussed in this section; the third, which addresses the four preclosure guidelines that require data from site characterization, is discussed in Section 6.3.2.

6.2.2.1 Preclosure system guideline: radiological safety (10 CFR 960.5-1(a)(1))

6.2.2.1.1 Introduction

The qualifying condition for this guideline is as follows:

Any projected radiological exposures of the general public and any projected releases of radioactive materials to restricted and unrestricted areas during repository operation and closure shall meet the applicable safety requirements set forth in 10 CFR Part 20, 10 CFR Part 60, and 40 CFR 191, Subpart A.

The system guideline on preclosure radiological safety is assigned the greatest importance among the preclosure guidelines because it is directed at protecting both the public and the workers at the repository from radiological exposures, as required by the performance objective of 10 CFR Part 60 (1983) for radiological safety. During the preclosure phase, this objective is achieved mainly through engineering technology (e.g., high-integrity structures, air-treatment systems, radiation monitors) and Nuclear Regulatory Commission (NRC)-approved operating procedures.

The system elements that must be considered in evaluations for this guideline are (1) the site characteristics that affect radionuclide transport through the surroundings; (2) the engineered components with the function to control releases of radioactive materials; and (3) the people who, because of their location and distribution in unrestricted areas, may be affected by radionuclide releases. Although details about its engineered components are not yet available, the repository will have to comply with the regulatory release limits. This compliance will have to be demonstrated to the satisfaction of the NRC, which will review both the engineering designs and operating procedures. Among the features that will contribute to operational safety will be the waste form (solid) and the waste package that will contain the radioactive materials and prevent their dispersal; high-efficiency air filters that will control airborne radioactive emissions into the atmosphere; and water-purification systems, which will be used to decontaminate any water used for the cleanup of facilities or components. Table 6-13 summarizes the finding for the qualifying condition. The remainder of this section summarizes the data available, presents an evaluation, and draws a conclusion.

Table 6-13. Summary of analyses for Section 6.2.2.1; preclosure system guideline: radiological safety (10 CFR 960.5-1(a)(1))

Condition	Department of Energy (DOE) finding
QUALIFYING CONDITION	
Any projected radiological exposures of the general public and any projected releases of radioactive materials to restricted and unrestricted areas during repository operation and closure shall meet the applicable safety requirements set forth in 10 Part 20, 10 CFR Part 60, and 40 CFR 191, Subpart A.	Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): preferential radionuclide transport to population centers is not expected; the site is in an area of low population density; the DOE will gain the necessary land ownership and control through interagency transfers; severe weather is infrequent and normally of short duration; and engineered components are expected to contain waste and retard radionuclide migration so that all applicable safety requirements are met.

8 0 0 0 8   0 6 3 5

6.2.2.1.2 Data relevant to the evaluation

Supporting data and information about the engineered components that will control releases of radioactive materials at the Yucca Mountain site are summarized in a preliminary safety assessment (Jackson et al., 1984). The safety assessment provides estimates of upper limits to potential doses from accidents at the repository; all the first-year estimated doses are total-body doses, derived by considering the body as a mass of undifferentiated tissue, rather than whole-body doses which are derived by weighting the doses to each affected organ and summing to produce an integrated dose to the body (Jackson et al., 1984). Population data for Nye and Clark counties were obtained from reports by the Clark County Department of Comprehensive Planning (1983) and Smith and Coogan (1984), respectively. Meteorologic data compiled by Bowen and Egami (1983), Holzworth (1972), and Quiring (1968, 1965) have been used to evaluate the potential for airborne radionuclide transport and dispersion. Studies by Winograd and Thordarson (1975) and Montazer and Wilson (1984) were used to evaluate the hydrogeology of Yucca Mountain. For relevant data supporting the technical guidelines that are used to provide a preliminary assessment of this system guideline, see the corresponding relevant data compilations.

In support of the evaluation made in this section, the preclosure performance of the repository is evaluated in Section 6.4.1, which presents a radiological safety assessment and the applicable radiation-protection standards from 10 CFR Part 20 (1984), 10 CFR Part 60 (1983), and 40 CFR 191, Subpart A (1985). This preliminary assessment, based on generic studies of repository operations, predicts the releases of radionuclides that may occur during normal operation of the repository.

6.2.2.1.3 Evaluation of the Yucca Mountain site

Those technical guidelines that contribute to the evaluation of this system guideline include population density and distribution (Section 6.2.1.2), site ownership and control (sections 6.2.1.1 and 6.2.1.3), meteorology (Section 6.2.1.4), and offsite installations and operations (Section 6.2.1.5). Evaluations of favorable and potentially adverse conditions in these technical guidelines are used as preliminary system-performance indicators that can be applied before site characterization.

The objective of the guideline on population density and distribution is to ensure that the site will meet the Environmental Protection Agency (EPA) and the Nuclear Regulatory Commission (NRC) regulations with minimum risk to the public. The area around the site is one of the most sparsely populated regions in the contiguous 48 states. Present site ownership and control provide the basis for limiting the entry of people onto the site during operation and closure. The eastern portion of the site is on the Nevada Test Site (NTS), which is controlled by the U.S. Department of Energy (DOE); the northwestern portion of the site is on the Nellis Air Force Range (NAFR), which is controlled by the Department of the Air Force; and the southwestern portion of the site is held in public trust by the Bureau of Land Management. It is expected that the DOE can acquire jurisdiction and control over the remaining portions of the land, including surface and subsurface rights.

There are no permanent residents within 10 kilometers (6 miles) of the site and all land within this radius is currently federally controlled and not open to settlement. Access to the NAFR and NTS is restricted. Nye County, where the Yucca Mountain site is located, had a 1980 population density of 0.5 person per square mile (Table 3-26). The nearest population center is located in the unincorporated Town of Amargosa Valley, whose residents are spread out in numerous small settlements within its estimated 1,036 square kilometers (400 square miles) (Section 6.4.1.1). Major population concentrations are located in the community formerly called Lathrop Wells, and now also called Amargosa Valley, approximately 23 kilometers (14 miles) to the south; the Amargosa Farm Area, approximately 37 kilometers (23 miles) to the south and the American Borate housing complex, roughly 45 kilometers (28 miles) to the south. Population of these areas in 1984 was estimated to be 45, 1500, and 280 respectively (Smith and Coogan, 1984). An estimate of the total population of the unincorporated Town of Amaragosa Valley is not available.

Beatty, located about 31 kilometers (19 miles) to the northwest had an 1984 estimated population of 800 (Smith and Coogan, 1984). Pahrump's 1984 population was estimated to 5,500 (Smith and Coogan, 1984). It is located slightly more than 80 kilometers (50 miles) to the southeast. The nearest highly populated area is in the Las Vegas Valley area about 137 kilometers (85 miles) by air southeast of Yucca Mountain. This is also the nearest 1 mile by 1 mile area having a population of at least 1,000 individuals (Clark County Department of Comprehensive Planning, 1983). All of the distances cited above are straight-line distances, not road distances.

Calculations for worst-case accident scenarios at Yucca Mountain have been completed. Preliminary results of a safety assessment study are available (Jackson et al., 1984). This study assumes that a person could be temporarily in an area 4 kilometers (2.5 miles) from the surface facilities. Assuming this person to be the maximally exposed individual, preliminary calculations for an extremely severe and unlikely accident at the repository estimate that the worst-case maximum individual total-body equivalent dose would be 0.055 rem, (0.068 rem 50-year dose commitment). For comparsion, the limit specified in 10 CFR Part 20 (1984) for normal operations is 0.5 rem per year for an individual in an unrestricted area. The worst-case accident-related radiation exposure of the 19,908 people conservatively assumed, for purposes of estimating worst-case dose, to live within 80 kilometers (50 miles) of the repository site at Yucca Mountain, is 110 man-rem, which is much less than the annual background-radiation external dose commitment of about 1,790 man-rem to the same number of people.

Radionuclides released to the environment can potentially be transported by both liquid and gaseous transport mechanisms. At the Yucca Mountain site, surface-water transport mechanisms are not considered likely, because of the aridity of the climate and the absence of surface water. The Yucca Mountain site is located in one of the most arid regions of the United States, with an average annual rainfall in the region of less than 150 millimeters (6 inches) (Quiring, 1965; Bowen and Egami, 1983). The arid conditions allow very limited infiltration and recharge (Winograd and Thordarson, 1975; Montazer and Wilson, 1984). Ground-water transport is not a reasonable release mechanism during the operation of the repository owing to the long ground-water travel time that is expected in the unsaturated zone (Section 6.3.1.1.5).

The potential for retardation of radionuclides in the zeolitized tuffaceous beds of the Calico Hills beneath the repository, and the great distance between the site and a down-gradient population center where ground water is withdrawn are also favorable conditions in this regard. The air pathway may therefore represent the most likely pathway of radionuclide travel during the period when gaseous radionuclides are present in the radioactive waste.

Table 6-46 in Section 6.4.1 provides estimates of expected radionuclide releases under normal repository operation for a generic repository. The maximum releases predicted were for krypton-85 and would result in an air concentration of 6.3×10^{-8} curie per cubic meter at the point of discharge. The concentration limit for krypton-85 from 10 CFR Part 20 (1984) is 3×10^{-7} curie per cubic meter. Dispersion between the discharge point and the site boundary is likely to further reduce the krypton-85 concentration. Other concentration estimates for tritium, carbon-14, and iodine-129 would also be below the limit from 10 CFR Part 20. The estimated annual dose equivalent for immersion in the dispersed cloud of airborne radionuclides listed in Table 6-46 is predicted to be less than 1.0 millirem per year (Section 6.4.1), which represents only about 1 percent of the dose received from natural background by an individual in the vicinity of the NTS.

Meteorological data from Yucca Flat (40 kilometers (25 miles)) east of Yucca Mountain) have been used to suggest that the site is well ventilated. Isopleths of mean annual mixing heights show that the region experiences some of the deepest atmospheric mixing in the United States (Holzworth, 1972). Surface winds are not likely to cause preferential transport toward regional population centers. Upper-air data from Yucca Flat for 1,500 and 1,800 meters (5,000 and 6,000 feet) above mean sea level (Quiring, 1968), which is beyond the influence of local terrain, show that wind from the northwest toward Las Vegas occurred only 11 percent of the time on an annual basis. Winds from the east, which would transport material toward Beatty, occurred only 2 percent of the time. Winds from the north, which would transport material toward the Town of Amargosa Valley, occurred approximately 20 percent of the time.

The 10-year record of wind speeds shows that the average wind velocity at Yucca Flat is high, 11.9 kilometers (7.4 miles) per hour (Bowen and Egami, 1983). Extreme weather phenomena are not likely to cause disruptions in repository operation or closure activities because southern Nevada has one of the lowest frequencies of severe weather in the United States, and the extreme events are generally of very short duration.

Site-specific meteorological data are insufficient to predict local wind directions at Yucca Mountain. These data will be collected by weather stations recently installed at Yucca Mountain. Data obtained over the next several years from new weather towers will be used to refine the radionuclide dispersion calculations that are currently based on data from Yucca Flat and to verify that Yucca Mountain conditions have been accurately predicted. As they are developed during the design process, details of the engineered components of the repository will be examined to determine whether the preliminary information used in evaluating the site against the technical guidelines was correct and to perform rigorous analyses of operational safety.

The impacts of nearby atomic energy defense activities that take place on the NAFR and the NTS are discussed under the guideline on offsite installations and operations. Airborne radionuclides from the NTS detected off the site from 1974 through 1983 are listed in Table 6-7. There were no detectable offsite radionuclide releases from nuclear weapons tests at the NTS during 4 out of 5 of the most recent 1-year monitoring periods. These releases are not regulated by 40 CFR Part 191 (1985).

6.2.2.1.4 Conclusion for the qualifying condition on the preclosure system guideline: radiological safety

A preliminary evaluation of the system elements pertinent to the system guideline on preclosure radiological safety shows that the characteristics of the site favor its ability to limit exposure to radiation among workers and the public; the distribution of people who live outside the area would also restrict exposures. Estimates of both the extreme worst-case accidental radiological exposures to the general public and the exposures due to normal operation are below the limits specified in 10 CFR Part 20 (1984), 10 CFR Part 60 (1983), and 40 CFR 191, Subpart A (1985). Estimated releases under normal repository operation (Section 6.4.1) produce radionuclide concentrations that are well below the maximum permissible concentrations. The evidence does not support a finding that the site is not likely to meet the qualifying condition for this preclosure system guideline (level 3).

6.2.2.2 Preclosure system guideline: environment, socioeconomics, and transportation (10 CFR 960.5-1(a)(2))

6.2.2.2.1 Introduction

The qualifying condition for this guideline is as follows:

During repository siting, construction, operation, closure, and decommissioning the public and the environment shall be adequately protected from the hazards posed by the disposal of radioactive waste.

The preclosure system elements for this guideline include (1) the interaction between repository-related activities and the existing economic, social, and demographic conditions of the area; (2) the air, land, water, plants, animals, and cultural resources in the areas potentially affected by repository activities; (3) the transportation infrastructure; and (4) the potential mitigation and compensation measures that can be used to offset adverse impacts. Table 6-14 summarizes the findings for the qualifying condition.

Table 6-14. Summary of analyses for Section 6.2.2.2; preclosure system guideline: environment, socioeconomics and transportation (10 CFR 960.5-1(a)(2))

Condition	Department of Energy (DOE) finding

QUALIFYING CONDITION

During repository siting, construction, operation, closure, and decommissioning the public and the environment shall be adequately protected from the hazards posed by the disposal of radioactive waste.

Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): there are no significant environmental impacts that cannot be mitigated; the socioeconomic welfare of the public can be preserved; transport of wastes can be conducted in compliance with regulations; the public and the environment will be adequately protected from the hazards posed by radioactive waste disposal.

6.2.2.2.2 Data relevant to the evaluation

The data used to evaluate the potential environmental impacts of the repository consist of (1) surveys and published reports on the biologic, archaeologic, and hydrologic conditions of the Yucca Mountain area (see Chapter 3); (2) analyses in Chapter 4 on the environmental consequences of site characterization; and (3) analyses in Chapter 5 on the near- and long-term environmental consequences of constructing, operating, closing, and decommissioning a nuclear waste repository at Yucca Mountain. Chapters 4 and 5 also present an evaluation of potential transportation impacts and preliminary evaluations of the socioeconomic impacts of site characterization and repository construction and operation at Yucca Mountain.

6.2.2.2.3 Evaluation of the Yucca Mountain site

The evaluation of the Yucca Mountain site against this system guideline is based on the evaluations reported for the technical guidelines for environmental quality (Section 6.2.1.6), socioeconomic impacts (Section 6.2.1.7), and transportation (Section 6.2.1.8).

As discussed in chapters 4 and 5, the potentially significant adverse environmental impacts associated with siting, constructing, operating, closing, and decommissioning a repository at Yucca Mountain include (1) destruction of approximately 680 hectares (1,608 acres) of desert habitat; (2) fugitive-dust emissions from surface preparation, excavation, and manipulation of spoils piles; (3) vehicle emissions from waste transport, personnel transport, materials transport, and operation of construction equipment; and (4) radioactive-material releases during (a) repository excavation (from naturally occurring radon and decay products in volcanic rocks), (b) normal operation of the repository, and (c) accidents. Potential impacts on surface and ground water are considered insignificant, chiefly because there is no perennial surface water in the area, and ground water is several hundred meters beneath the repository horizon (Section 6.3.1.1). A permanent land withdrawal will be required if the Yucca Mountain site is selected for repository development, and the reservation of water rights is explicit in such an action. Studies to date suggest that aquifers underlying the proposed surface facility locations can produce large quantities of water for long time periods without lowering the regional ground-water table. Other potential impacts, such as the diversion of natural runoff and the leaching of materials from excavated rock, are being considered in the repository design, and they are not expected to pose significant environmental problems.

During repository construction, the maximum estimated ambient concentrations of particulates, carbon monoxide, and the oxides of sulfur and nitrogen are not expected to exceed the air-quality limits of 40 CFR Part 50 (1983). Assuming the project is subject to the Prevention of Significant Deterioration provisions of the Clean Air Act Amendments of 1977, the predicted pollutant concentrations would violate none of the applicable standards.

The evaluations of the socioeconomic impacts guideline in Section 6.2.1.7 are briefly summarized below.

Negative impacts on community services, housing supply and demand, and the finances of State and local government agencies in the affected area are

not expected to be significant for repository siting, construction, operation, and decommissioning.

The maximum 1-year percent increase in the bicounty population would occur during the second year of construction (1994). The maximum 1-year percent increase is estimated to be 4.0 percent for Nye County and 3.7 percent for Clark County. The affected (bicounty) area, including the Las Vegas Valley, has the ability to absorb the repository-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand.

Although community-specific service and housing demands could increase at rates proportional to the maximum 1-year community population growth rates estimated with the repository, these rates are generally within the range of those experienced historically by the urban communities (approximately 2.7 to 13.2 percent) and their municipal service providers. Because the unincorporated towns nearest the Yucca Mountain site have limited powers dealing with community services, potential population growth in these communities would generally impact county-wide service providers. These service providers are more likely to have resources for managing growth. Additionally, the community level growth rates estimated for the unincorporated towns are generally within range of those experienced historically by Nye and Clark counties (tables 3-15 and 3-16). Ample land is available for housing in the rural communities closest to the Yucca Mountain site.

The primary sectors of the economy in southern Nevada are tourism and mining. The employment impacts of site characterization on these sectors are expected to be insignificant. Information available to date does not suggest that repository construction and operation would significantly affect tourism. Construction and operation of a repository would significantly increase employment in mining and moderately increase employment in construction. These employment increases are not considered to represent major disruptions of these sectors.

The work force in southern Nevada, including the Las Vegas Valley, is sufficiently large to site, construct, and operate a repository at Yucca Mountain. Although an adequate total work force may be available for a repository at Yucca Mountain, the available work force with mining skills would be inadequate and it is possible that the available construction work force may also be inadequate.

A repository at Yucca Mountain would increase employment and business sales in southern Nevada. Community services and government revenues are likely to increase.

In summary, preliminary analyses of labor demand, materials and resources, income, and land use reveal no potentially significant adverse impacts. It is expected that impacts on State and local community infrastructure discussed in Section 5.4 can be offset by reasonable mitigation or compensation under the financial and technical assistance provisions of the Nuclear Waste Policy Act (NWPA, 1983). The U.S. Department of Energy (DOE) maintains a commitment to consult and cooperate with responsible State and local governments in identifying specific areas where adverse impacts could

occur and in developing appropriate measures of corrective action and mitigation.

For rail access to Yucca Mountain, a rail line extending approximately 161 kilometers (100 miles) from existing mainline rail facilities at Dike Siding (northeast of Las Vegas) has been proposed (see Figure 5-2). This route would be entirely on government-controlled lands administered by the DOE and the U.S. Department of the Air Force, as well as public-domain lands under the jurisdiction of the Bureau of Land Management.

The terrain over which the rail line would cross is gently sloping. No tunnels and only a minor amount of excavation and fill would be required. A bridge would be required at Fortymile Wash several miles east of Yucca Mountain. The construction of the proposed rail line from the site to Dike Siding would provide direct access to the national railroad system.

For highway access to the proposed site, a route is projected northward from U.S. Highway 95, originating approximately 1 kilometer (0.5 mile) west of the intersection of U.S. Highway 95 and Nevada State Route 373. U.S. Highway 95 is a regional highway providing access to the Interstates 15, 40, and 80, which are all part of the national transportation system. The roadway access would be constructed on federally controlled lands that slope gently and would pose no significant engineering problems. No tunnels and only a minor amount of excavation would be required. Some minor drainage control measures and a bridge spanning Fortymile Wash would be required. The bridge would be a common carrier for both rail and truck access. U.S. Highway 95 between Las Vegas and Mercury is a four-lane divided highway; it is a two-lane highway from Mercury to the access road near intersection of U.S. Highway 95 and Nevada State Route 373. A requirement for significant upgrading of this regional highway is unlikely.

A legal impediment could only exist if State, local, or tribal law rendered compliance with U.S. Department of Transportation (DOT) regulations impossible, without being found preempted by the (DOT) or the Federal judicial system. California time-of-day requirements and the banning of radioactive waste shipments in Humboldt and Marin counties as well as the recently passed Las Vegas, Nevada, ordinance (No. 3190) are the only regulations that could be considered an impediment to waste shipments. However, these regulations are considered preempted by DOT regulations until they are allowed to stand by either the DOT or the Federal judicial system.

6.2.2.2.4 Conclusion for the qualifying condition on the preclosure system guideline: environment, socioeconomics and transportation

The repository and its support facilities could be sited, constructed, operated, closed, and decommissioned at Yucca Mountain while protecting the public and the environment from the hazards posed by disposal of radioactive waste. Furthermore, measures to offset, mitigate, or compensate projected environmental impacts and significant adverse social and economic impacts exist or are expected to be developed through a process of analysis, planning, and consultation among the DOE, affected State, and local government jurisdictions. Efforts will be made to preserve the socioeconomic welfare of

the general public in the affected area and to protect the socioeconomic welfare and the aesthetic values of the region. The projected risks, costs, and other impacts of waste transportation are being considered in the evaluation of the Yucca Mountain site, and there is no evidence to suggest that transportation of wastes cannot be conducted in compliance with applicable Federal regulations, and with State and local regulations that are applicable and consistent with these Federal regulations. Analyses of worst-case operational and nonoperational accidents at a potential repository at Yucca Mountain indicate that population exposures would be small compared to natural background sources. The evidence does not support a finding that the site is not likely to meet the qualifying condition of the preclosure system guideline (level 3).

6.2.3 CONCLUSION REGARDING SUITABILITY OF THE YUCCA MOUNTAIN SITE FOR DEVELOPMENT AS A REPOSITORY

On the basis of the findings stated in the previous discussion of individual guidelines and made in accordance with Appendix III of the siting guidelines (10 CFR Part 960, 1984), it is concluded that the evidence does not support a finding that the site is disqualified and does not support a finding that the site is not likely to meet the qualifying conditions. Therefore, it is concluded on the basis of those guidelines that do not require data and information from site characterization that there is no reason to believe that the Yucca Mountain site is not suitable for development as a repository.

6.3 SUITABILITY OF THE YUCCA MOUNTAIN SITE FOR SITE CHARACTERIZATION: EVALUATION AGAINST THE GUIDELINES THAT DO REQUIRE SITE CHARACTERIZATION

This section presents preliminary evaluations of the Yucca Mountain site against the twelve technical and the two system guidelines that require data from site characterization for a determination of compliance. The post-closure guidelines are discussed first, in sections 6.3.1 (technical guide-lines) and 6.3.2 (system guidelines). The preclosure guidelines are covered in sections 6.3.3 (technical guidelines) and 6.3.4 (system guidelines).

6.3.1 POSTCLOSURE TECHNICAL GUIDELINES (10 CFR 960.4-2)

The postclosure technical guidelines address the site conditions that are related to the long-term performance of the repository. They address geohydrology, geochemistry, rock characteristics, climatic changes, erosion, dissolution, tectonics, and human interference. For each technical guide-line, an introduction describes the objective of the guideline and refers to a table that states the entire guideline and summarizes the evaluations. After a description of the relevant data, a series of evaluations show whether the Yucca Mountain site is likely to possess the favorable,

potentially adverse, disqualifying, and qualifying condition(s) that are included in the guideline.

6.3.1.1 Geohydrology (10 CFR 960.4-2-1)

6.3.1.1.1 Introduction

The qualifying condition for this guideline is as follows:

The present and expected geohydrologic setting of a site shall be compatible with waste containment and isolation. The geohydrologic setting, considering the characteristics of and the processes operating within the geologic setting, shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered barrier system using reasonably available technology.

The geohydrology guideline addresses the present and expected characteristics of the geohydrologic setting of the site and processes operating within this geohydrologic setting; it requires that these characteristics and processes be compatible with waste containment and isolation. After repository closure, the most likely mechanism for the release of radionuclides from a repository to the accessible environment is transport by ground water. To evaluate this potential for release in the postclosure time period, it is necessary to characterize the volume, flow paths, velocities, and travel times for ground water.

This guideline consists of five favorable conditions, three potentially adverse conditions, one disqualifying condition, and one qualifying condition. The evaluations reported below are summarized in Table 6-15 for all conditions except the disqualifying condition.

6.3.1.1.2 Data relevant to the evaluation

Summary of available data

Because a repository at Yucca Mountain would be above the water table, discussions about radionuclide movement must consider unsaturated rocks as well as saturated rocks. The geohydrologic system at Yucca Mountain is composed of a thick (about 300 to 750 meters (1,000 to 2,500 feet)) unsaturated section and a deep saturated-flow regime. The relevant data for analyzing the saturated system include the standard hydrologic parameters of permeability (or similar parameters such as transmissivity and hydraulic conductivity), hydraulic gradient, effective porosity, and water flux. For the unsaturated zone, the same parameters are needed, but they must be augmented with information on infiltration and percolation rates, the moisture content of the rock, and the relationship of moisture content or saturation to matric potential (suction) and hydraulic conductivity. For both the saturated and unsaturated zones, an understanding of the spatial distribution of these

Table 6-15. Summary of analyses for Section 6.3.1.1; geohydrology (10 CFR 960.4-2-1)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITIONS	
(1) Site conditions such that the pre-waste-emplacement ground-water travel time along any path of likely radionuclide travel from the disturbed zone to the accessible environment would be more than 10,000 years.	The evidence indicates that this favorable condition is present at Yucca Mountain: ground-water travel time along any path of likely radionuclide travel is expected to be more than 10,000 years.
(2) The nature and rates of hydrologic processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.	The evidence indicates that this favorable condition is not present at Yucca Mountain: pluvial conditions that could cause changes in the water-table position and increase flux are expected to affect, but not significantly reduce, isolation potential in the next 100,000 years.
(3) Sites that have stratigraphic, structural, and hydrologic features such that the geohydrologic system can be readily characterized and modeled with reasonable certainty.	The evidence indicates that this favorable condition is not present at Yucca Mountain: no features are known that would prevent the site from being characterized and modeled after site characterization but available data are insufficient to model the site with reasonable certainty.
(4) For disposal in the saturated zone, at least one of the following pre-waste-emplacement conditions exists:	Condition does not apply to Yucca Mountain.

Table 6-15. Summary of analyses for Section 6.3.1.1; geohydrology (10 CFR 960.4-2-1) (continued)

Condition	Department of Energy (DOE) finding
(i) A host rock and immediately surrounding geohydrologic units with low hydraulic conductivities.	Condition does not apply to Yucca Mountain.
(ii) A downward or predominantly horizontal hydraulic gradient in the host rock and in the immediately surrounding geohydrologic units.	Condition does not apply to Yucca Mountain.
(iii) A low hydraulic gradient in and between the host rock and the immediately surrounding geohydrologic units.	Condition does not apply to Yucca Mountain.
(iv) High effective porosity together with low hydraulic conductivity in rock units along paths of likely radionuclide travel between the host rock and the accessible environment.	Condition does not apply to Yucca Mountain.
(5) For disposal in the unsaturated zone, at least one of the following pre-waste-emplacement conditions exists:	The evidence indicates that three of five of the subconditions of this favorable condition are present at Yucca Mountain:
(i) A low and nearly constant degree of saturation in the host rock and in the immediately surrounding geohydrologic units.	The degree of saturation in the host rock and surrounding geohydrologic units is spatially variable. Therefore, the subcondition is not present.

Table 6-15. Summary of analyses for Section 6.3.1.1; geohydrology (10 CFR 960.4-2-1) (continued)

Condition	Department of Energy (DOE) finding
(ii) A water table sufficiently below the underground facility such that the fully saturated voids continuous with the water table do not encounter the host rock.	The host rock contains no fully saturated voids that are continuous with the water table. Therefore, the subcondition is present.
(iii) A geohydrologic unit above the host rock that would divert the downward infiltration of water beyond the limits of the emplaced waste.	The bedded tuffs above the densely welded host rock may divert pulses of water, but not necessarily beyond limits of emplaced waste. Therefore, the subcondition is not present.
(iv) A host rock that provides for free drainage.	The host rock is expected to be freely draining. The subcondition is present.
(v) A climatic regime in which the average annual historical precipitation is a small fraction of the average annual potential evapotranspiration.	Precipitation in the area is about 20 percent of the potential evapotranspiration. Therefore, the subcondition is present.

POTENTIALLY ADVERSE CONDITIONS

(i) Expected changes in geohydrologic conditions— such as changes in the hydraulic conductivity, the hydraulic gradient, porosity and the ground-water flux through the host rock and the surrounding geohydrologic units—sufficient to significantly increase the transport of radionuclides to the accessible environment as compared with pre-waste-emplacement conditions.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: expected changes in geohydrologic conditions are not likely to cause significant increase in transport of radionuclides.

Table 6-15. Summary of analyses for Section 6.3.1.1; geohydrology (10 CFR 960.4-2-1) (continued)

Condition	Department of Energy (DOE) finding
(2) The presence of ground-water sources, suitable for crop irrigation or human consumption without treatment, along ground-water flow paths from the host rock to the accessible environment.	The evidence indicates that this potentially adverse condition is present at Yucca Mountain: ground-water sources suitable for crop irrigation or human consumption are present along the ground-water flow paths, although resource potential is small.
(3) The presence in the geologic setting of stratigraphic or structural features—such as dikes, sills, faults, shear zones, folds, dissolution effects, or brine pockets—if their presence could significantly contribute to the difficulty of characterizing or modeling the geohydrologic system.	The evidence indicates that this potentially adverse condition is present at Yucca Mountain: fractures, fault zones, and dikes could contribute to the difficulty of characterizing and modeling the system.

QUALIFYING CONDITION

The present and expected geohydrologic setting of a site shall be compatible with waste containment and isolation. The geohydrologic setting, considering the characteristics of and the processes operating within the geologic setting, shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.	Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): radionuclide release is expected to be less than one part in 100,000 of the 1,000 year inventory; ground-water flow time is likely to be more than 10,000 years; the low magnitude of ground-water flux limits potential release of radionuclides.

properties is needed. This, in turn, requires a knowledge of the stratigraphy and structure of the proposed site, including the dip, character, thickness, depth, and lateral variations of the rock units and the frequency and orientations of fractures, faults, and other structures.

Five drill holes at Yucca Mountain (UE-25a#1, USW G-1, USW G-2, USW G-3/GU-3, and USW G-4) have been continuously cored to depths ranging from 760 to 1,825 meters (2,500 to 6,000 feet) (Spengler et al., 1979, 1981; Spengler and Chornack, 1984). Stratigraphic descriptions have been published for several of these holes (Spengler and Chornack, 1984; Maldonado and Koether, 1983; Scott and Castellanos, 1984). Test hole UE-25b#1 was cored from 579 to 1,220 meters (1,900 to 4,000 feet) (Lahoud et al., 1984). One test hole (UE-25p#1) penetrated pre-Tertiary rocks (Craig and Johnson, 1984) and provided both cuttings and core samples of Paleozoic rocks that underlie the section of Tertiary rocks east of Yucca Mountain (Craig and Robison, 1984). Rock property analyses of core samples from UE-25a#1 are available in Anderson (1981a). In addition, cuttings and cores from many nearby hydrologic test holes provided additional data on the positions of stratigraphic contacts. A summary of geologic studies at the Yucca Mountain site is presented in USGS (1984).

Test holes for hydrologic conditions include 14 holes that have been drilled to provide data on the altitude of the water table (Robison, 1984) and 3 holes drilled in the immediate vicinity of Yucca Mountain for pump and packer-injection tests (Rush et al., 1984; Lahoud et al., 1984; Craig and Robison, 1984). Data are also available from two deep test holes in the unsaturated zone, USW UZ-1 and USW UZ-6 (Henderson and Benson, 1983; Whitfield, 1985). Both were drilled using reverse-air vacuum drilling techniques, and core and cuttings were obtained. USW UZ-1, drilled to 366 meters (1,200 feet) has been instrumented to obtain potentiometric and moisture-content data. Plans are to install similar instrumentation in USW UZ-6, drilled to 579 meters (1,900 feet). Table 6-16 summarizes the published reports available on the saturated zone hydrologic drill holes at Yucca Mountain. Paleohydrologic data from the vicinity of Yucca Mountain are also available (Winograd and Doty, 1980).

A geologic map of Yucca Mountain shows patterns of structural features (Scott and Bonk, 1984). The major normal faults that subdivide the geologic setting of Yucca Mountain into a series of blocks tilted slightly to the east have been known for more than 20 years (Christiansen and Lipman, 1965; Lipman and McKay, 1965); they fit the descriptions of typical basin and range faults that occur elsewhere in the Great Basin (Scott et al., 1984). Major normal faults that have a vertical displacement of more than 70 meters (230 feet) have been identified on the basis of aeromagnetic surveys (Bath and Jahren, 1984) and can in some places be located where they occur under alluvium. The attitudes of faults and fractures at depth in drill holes are similar to those on the surface (Scott and Bonk, 1984; Scott and Castellanos, 1984). Quaternary movement on faults in the vicinity of Yucca Mountain has been investigated, and the results are summarized in Swadley et al. (1984). Fault-related mineral deposits, found in the Yucca Mountain area and their origin are discussed in Vaniman et al. (1985). Other references on the nature and rates of tectonic activity at Yucca Mountain are discussed in Section 6.3.1.7.

Table 6-16. Published geohydrologic well reports

Well	Data Reports	Interpretive Reports
USW H-1	Rush et al., 1983	Rush et al., 1984; Barr, 1985
USW H-3	Thordarson et al., 1984	Thordarson et al., 1985
USW H-4	Whitfield et al., 1984	Erickson and Waddell, 1985; Whitfield et al., 1985
USW H-5	Bentley et al., 1983	-----
USW H-6	Craig et al., 1983	-----
UE-25b#1	Lobmeyer et al., 1984	Lahound et al., 1984
UE-25p#1	Craig and Johnson, 1984	Craig and Robison, 1984
UE-29a#1,2	-----	Waddell, 1985
USW G-4	Bentley, 1984	-----
Well J-13	-----	Thordarson, 1983

The hydrostratigraphy of tuffs in the unsaturated zone (see discussion of geologic units in tables 6-17 and 6-18 in Section 6.3.1.1.5) consists of the following hydrogeologic units: the Tiva Canyon welded unit, the Paintbrush nonwelded unit, the Topopah Spring welded unit (including the proposed repository horizon), the Calico Hills nonwelded vitric unit, the Calico Hills nonwelded zeolitic unit, the Prow Pass welded unit, the Prow Pass nonwelded unit, the Bullfrog welded unit, and the Bullfrog nonwelded unit. Not all hydrogeologic units are present at any given location within the primary repository area at Yucca Mountain.

The Tiva Canyon welded hydrogeologic unit is the densely to moderately welded part of the Tiva Canyon Member of the Paintbrush Tuff. This unit is the uppermost stratigraphic layer that underlies much of Yucca Mountain. The Paintbrush nonwelded hydrogeologic unit consists of the nonwelded and partially welded base of the Tiva Canyon Member, the Yucca Mountain Member, the Pah Canyon Member, and associated bedded tuffs, all part of the Paintbrush Tuff. The lithology of this hydrogeologic unit is mostly thin, nonwelded ash-flow sheets and bedded tuffs, and in the primary repository area, the unit crops out only in a narrow band along Solitario Canyon (Montazer and Wilson, 1984).

The Topopah Spring welded hydrogeologic unit consists of a very thin upper vitrophyre, a thick central zone consisting of several densely welded devitrified ash-flow sheets, and a thin lower vitrophyre. The unit is highly fractured, and contains several lithophysal cavity zones (Montazer and Wilson, 1984).

The Calico Hills nonwelded unit is composed of the following stratigraphic units: the nonwelded base of the Topopah Spring Member; the tuffaceous beds of the Calico Hills which contain both zeolitic and vitric facies, and the upper part of the Prow Pass Member (Montazer and Wilson, 1984). Fracture frequency within this unit is much lower than in the overlying Topopah Spring welded unit. The water table is generally below the Calico Hills nonwelded unit, except beneath the eastern part of Yucca Mountain. Moisture flux beneath the repository horizon is quite low; an upper bound on the estimated range of flux is 0.5 millimeter (0.02 inch) per year (Wilson, 1985).

Two-dimensional modeling of flow in the saturated zone on a regional scale has been performed (Waddell, 1982; Czarnecki, 1985; Czarnecki and Waddell, 1984). Regional data for this modeling have been obtained from Winograd and Thordarson (1975). Hydrologic and hydraulic data in the immediate vicinity of Yucca Mountain have been obtained by the following methods, and are documented in the following sources. Bulk saturated hydraulic conductivity of the Topopah Spring welded unit is known from pumping tests in Well J-13 (Thordarson, 1983) where this unit occurs in the saturated zone. The results of pumping tests and packer-injection tests on three test holes in the immediate vicinity of Yucca Mountain are presented by Rush et al. (1984), Lahoud et al. (1984), and Craig and Robison (1984). In addition, 14 other test holes have been drilled that provide data on altitude of the water table (Robison, 1984). Bulk and fracture effective porosities in the saturated zone have been calculated and are reported by Sinnock et al. (1984). Information provided in Freeze and Cherry (1979) was used in the calculation of effective porosities.

A general conceptual model for flow through the unsaturated zone has also been developed (Scott et al., 1983; Montazer and Wilson, 1984). A stochastic model for calculation of velocities and travel time in the unsaturated zone was developed by Sinnock et al. (1986), and information from Brooks and Corey (1966) was used to account for the effect of pore-size distribution on velocity. Information concerning the in situ distribution of moisture in the unsaturated formations at Yucca Mountain is available from various boreholes (Weeks and Wilson, 1984; Montazer and Wilson, 1984; Palaz, 1985; Peters et al., 1984; Montazer et al., 1985). Rock-mass permeabilities to air in the Topopah Spring Member are summarized in Montazer and Wilson (1984) and are considered to be an indirect indication of the potential for drainage (Montazer, 1982). Porosity values for the tuffaceous beds of the Calico Hills, which underlie the Topopah Spring Member, are given by Weeks and Wilson (1984), Montazer and Wilson (1984), and Peters et al. (1984). The matrix hydraulic conductivity of the Topopah Spring unit, as well as of other units, has been obtained from laboratory measurements of cores and cuttings (Montazer and Wilson, 1984). Saturated matrix hydraulic conductivity values for the Calico Hills unit and for the Prow Pass and Bullfrog members of the Crater Flat Tuff have been obtained from the Tuff Data Base (SNL, 1985). Laboratory tests indicate that a relationship may exist between matrix

hydraulic conductivity and lithology (Lappin et al., 1982). Data presented in Blankennagel and Weir (1973) demonstrate this relationship for tuffs beneath Pahute Mesa. Additional hydrogeologic data is presented in Winograd and Thordarson (1975).

Meteorological data from several stations in the region are presented by Bowen and Egami (1983) and Quiring (1983). Potential evapotranspiration for Yucca Mountain has been estimated by an empirical method reviewed in Rosenberg (1974). Climates of the Nevada Test Site and vicinity during the last 45,000 years have been reconstructed in Spaulding (1983) and Spaulding et al. (1984). Possible climatic responses to increases in atmospheric carbon dioxide are presented in Kukla and Gavin (1981) and Etkins and Epstein (1982). The influence of earth's orbital variations on climatic changes is discusssed in Imbrie and Imbrie (1980). Other relevant climatological data are presented in Section 6.3.1.4, Climatic changes. A water-budget study for eastern Nevada is described by Eakin et al. (1951). The study utilizes a technique developed by Maxey and Eakin (1949) to estimate ground-water recharge. In Rush (1970), the technique was applied to estimate average annual recharge for basins in the Nevada Test Site area. The method described by Eakin et al. (1951) has been evaluated in Watson et al. (1976). An estimate of the water resource potential beneath Yucca Mountain is provided in Sinnock and Fernandez (1982).

Assumptions and data uncertainties

The principal assumptions that must be made about the hydrologic system of Yucca Mountain involve the amount of recharge, the related ground-water flux through the unsaturated zone, and the mechanisms by which water moves in the unsaturated tuffs. There is uncertainty about the most representative values for hydraulic conductivities, moisture contents, and effective porosities of the various rock units traversed by the subsurface water at Yucca Mountain. Effective porosities are subject to considerable uncertainty. To compensate for the inherent uncertainty in the existing information, most assumptions in this section are conservative, and, thus, they are believed to reasonably bound the probable range of hydrologic behavior at Yucca Mountain. Therefore, despite the uncertainty about the exact conditions and processes of the hydrologic system at Yucca Mountain, especially in the unsaturated zone, the conservatism of the assumptions and analyses allows confidence in the general conclusions about the hydrologic system.

A general conceptual model of flow in the unsaturated zone has been developed (Montazer and Wilson, 1984). The model is based on (1) current understanding of the hydrogeologic framework, (2) application of the principles of unsaturated flow, and (3) interpretation of preliminary data from ongoing field and laboratory investigations. The conceptual model is presented as a single comprehensive model, but it is broad enough and flexible enough to accommodate various alternative hypotheses for unsaturated flow conditions. These hypotheses are being tested by computer simulations that incorporate realistic ranges of input parameters and boundary conditions.

The results of both quantitative and qualitative analyses are used in the following discussions. Quantitative analyses are used to predict (1) the

expected ground-water travel time from the repository to the accessible environment in the evaluation against the disqualifying condition and (2) the expected releases of radionuclides to the accessible environment in the evaluation against the qualifying condition. Qualitative analyses are used to establish whether Yucca Mountain possesses the several favorable and potentially adverse conditions. Semiquantitative analyses are used in these evaluations to help draw conclusions from the information collected about the site and to incorporate other pertinent information from reasonable natural analogs of the site. For purposes of interpreting the favorable condition for ground-water travel time, the current position expressed by the Nuclear Regulatory Commission regarding extreme values in travel-time distribution (Browning, 1985) was considered in the analysis.

6.3.1.1.3 Favorable conditions

(1) Site conditions such that the pre-waste-emplacement ground-water travel time along any path of likely radionuclide travel from the disturbed zone to the accessible environment would be more than 10,000 years.

Evaluation

A complete discussion of the calculation of ground-water travel time at Yucca Mountain is included in the disqualifying condition evaluation (Section 6.3.1.1.5). The stochastic approach taken to evaluate ground-water travel time produces a distribution of possible travel times. The distribution results from natural variability and uncertainty in the hydrologic parameters. Conservative assumptions built into the flow model serve to shift the distribution to lower travel times. The extreme upper and lower portions of the travel-time distribution are characteristic of travel times along unlikely paths of radionuclide travel and therefore are inappropriate for evaluating this favorable condition. The U.S. Department of Energy (DOE) considers this judgment to be consistent with the Nuclear Regulatory Commission (NRC) staff position regarding the ground-water travel time requirement in 10 CFR Part 60 (Browning, 1985).

At this stage, the selection of an absolute value for the probability of travel times greater than 10,000 years is not warranted. The data base resulting from site characterization will permit better parameter estimation with less uncertainty and a more realistic construction of the travel-time model. These improvements are expected to narrow the range of travel times sufficiently to allow consideration of an appropriate probability value.

For the interim, a measure of central value of the travel-time distribution is considered appropriate for evaluating the potential site against this favorable condition. The mean is a mathematical approximation of the expected travel time (Davenport, 1970), and the median is also a measure of central value. For this reason, both mean and median values are provided in this evaluation, and both exceed 10,000 years. For the upper bound to the estimated range of flux through the repository of 0.5 millimeter (0.02 inch) per year, the mean travel time is approximately 43,405 years; the median travel time is about 41,750 years; and the range of travel times between the

disturbed zone and the accessible environment is from about 9,500 to 80,235 years (Table 6-20). These travel times include 140 years estimated for a 5-kilometer (3-mile) flow path in the saturated zone.

Ten computer realizations of travel time were made for each of 963 columns which represent the rock volume between the disturbed zone and the water table. Of the 9,630 realizations of travel time, 9,629 resulted in travel-time values greater than 10,000 years. Only one out of 9,630 realizations of the travel-time model resulted in a travel time less than 10,000 years. Therefore, for purposes of this evaluation the evidence indicates that this favorable condition is present.

Conclusion

Available data and current understanding of the geohydrologic system indicate that for the estimated upper bound on flux of 0.5 millimeter (0.02 inch) per year, the travel time along any path of likely radionuclide travel from the disturbed zone to the accessible environment is greater than 10,000 years. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(2) The nature and rates of hydrologic processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.

Evaluation

The Quaternary Period was characterized by cyclic fluctuations of climate, with wetter, cooler pluvial periods alternating with dryer, warmer interpluvial periods. Thus, at times, changes in hydrologic phenomena were related to increases in the available moisture, and, at other times, changes were associated with drying conditions. The principal changes in hydrologic processes that are associated throughout the Quaternary with the onset of pluvials occurred most recently about 9,000 to 13,000 years ago and probably included increasing recharge and a rising water table, with attendant changes in hydraulic gradients and the upgradient movement of ground-water discharge sites. Quaternary climatic conditions are described in more detail in Section 6.3.1.4 (Climatic changes).

The most recent climatic trend results from the shift from pluvial to interpluvial conditions that has led to the conditions observed today (Winograd and Doty, 1980). This trend (decreasing recharge, declining water table, and down-gradient shifts in ground-water discharge sites), if continued, would be likely to affect favorably the isolation capability of the repository. For the Ash Meadows ground-water basin, Winograd and Doty (1980) cited calcitic vein fracture fillings and ancient lakebed deposits as evidence that the water-table altitude in the regional carbonate aquifer during past pluvial conditions may have been as much as 50 meters (160 feet) higher than the modern level. Preliminary modeling results (Czarnecki, 1985) using the regional hydrologic models developed by Waddell (1982) and Czarnecki and Waddell (1984) suggest that water-table altitudes at and near

Yucca Mountain could possibly rise in the future as much as 130 meters (426 feet) above the current position of the water table. The simulation that predicted a water-table rise of this magnitude was based on assumptions that are conservative and may not be realistic (see Section 6.3.1.4.3). Nevertheless, cyclic fluctuations in climate are expected to continue and pluvial conditions are likely to return in the 100,000 year time frame covered by this favorable condition. Although there is considerable uncertainty in the changes that would occur during a return to pluvial conditions, increased recharge and increases in water-table altitude are likely in some portions of the Death Valley ground-water system. These changes would be unlikely to favorably affect the ability of a repository at Yucca Mountain to isolate waste.

Other processes of interest during the Quaternary are discussed in the evaluation of the geochemistry guideline (Section 6.3.1.2) and the erosion guideline (Section 6.3.1.5). According to those discussions, the past rates of other processes that depend on hydrologic processes, such as erosion, mineral dissolution, and mineral precipitation, remained at a low and relatively constant rate during the Quaternary Period.

Conclusion

The nature and rates of the hydrologic processes that operated at Yucca Mountain during the Quaternary Period were influenced by cyclic fluctuations in precipitation and a possible trend of increasing aridity. The nature and the rates of these processes if continued into the future could have an effect on the ability of the geologic repository to isolate radioactive waste during the next 100,000 years. Increased flux together with increased water table altitude could shorten the travel time through the unsaturated portion of the flow path, thus decreasing the total travel time to the accessible environment. Therefore, the evidence indicates that this favorable condition is not present at Yucca Mountain.

(3) Sites that have stratigraphic, structural, and hydrologic features such that the geohydrologic system can be readily characterized and modeled with reasonable certainty.

Evaluation

The geologic setting of Yucca Mountain is complex, with rocks ranging in age from Precambrian through Holocene, and the area has undergone many periods of structural deformation. Because of the weapons testing at the Nevada Test Site since the early 1960s, extensive geologic, geophysical, and hydrologic studies have been completed, and the geology and hydrology of the Nevada Test Site region are well documented. Extensive study of the nearby Yucca Mountain area started in 1978. Since that time, the geologic and hydrologic knowledge of the Yucca Mountain area has been greatly expanded.

Yucca Mountain is composed of block-faulted Tertiary ash-flow, air-fall, and bedded tuffs. The material properties used to model the geohydrologic system (e.g., porosity, matrix permeability, fracture permeability, relationships between moisture content and matric potential, and geochemical characteristics) vary substantially in this type of geologic setting. Although regional ground-water flow has been modeled (Waddell, 1982; Czarnecki and

Waddell, 1984), the physics of moisture movement in thick, unsaturated, fractured rocks is complex, and only preliminary conceptual models are available (Scott et al., 1983; Montazer and Wilson, 1984).

The general stratigraphic features of Yucca Mountain are well known as a result of studies listed in the section on relevant data. The general structural character of Yucca Mountain is also well known. Geologic maps of Yucca Mountain show patterns of structural features (Scott and Bonk, 1984; Christiansen and Lipman, 1965; Lipman and McKay, 1965). The attitudes of faults and fractures that are observed at depth in drill holes correlate well with those on the surface (Scott and Bonk, 1984; Scott and Castellanos, 1984). Thus, major surface structural features can be used to characterize the subsurface stratigraphy and geologic structures, the details of which would be determined during site characterization.

A relationship between lithology and permeability, based on well yields for welded tuffs, rhyolites, and bedded tuffs beneath eastern Pahute Mesa was demonstrated by Blankennagel and Weir (1973). A similar relationship may exist at Yucca Mountain. Laboratory tests of cores from both geologic and hydrologic test holes (Anderson, 1981a; Lappin et al., 1982; Peters et al., 1984; Rush et al., 1984; Weeks and Wilson, 1984) indicate that the porosity and the hydraulic conductivity of the matrix decrease as the degree of welding increases; however, fracture porosity increases and bulk permeability may increase with increased welding. Winograd and Thordarson (1975) and Scott et al. (1983) conclude that fracture frequency increases with the degree of welding.

These data and observations, together with the stratigraphic and structural data, have been used to develop conceptual models for flow through the unsaturated zone (Scott et al., 1983; Montazer and Wilson, 1984). These conceptual models represent the current hypotheses of the framework and dynamics of the flow system and are derived from preliminary data, from principles of saturated and unsaturated flow, and from the literature. The conceptual models form the basis upon which computer models and simple mathematical models are designed. Alternative concepts of flow can be tested with the models to derive the system with the framework, boundary, and flow characteristics that conform best with the observed data.

Hydrologic testing of the saturated zone has been performed on three test holes in the immediate vicinity of Yucca Mountain. These tests have included pumping tests of all or part of the saturated zone penetrated by the wells and packer-injection tests of isolated intervals within the holes. Both hydraulic-conductivity and water-level data have been collected. The results are presented by Craig and Robison (1984), Rush et al. (1984), and Lahoud et al. (1984). In addition, 14 other holes provided data on the altitudes of the water table (Robison, 1984). The results of these studies show that in the saturated zone at Yucca Mountain, ground water flows mainly through fractures in the welded tuffs. Productive intervals in test holes are controlled mostly by the distribution of permeable fractures that are intercepted by the hole rather than by stratigraphic position in the densely welded units. Therefore, attempts using only testing results to define the position or spatial extent of hydrogeologic units have not been successful. However, a relationship between lithology and fracture frequency at Yucca

Mountain has been documented by Scott et al. (1983) and may allow the general distribution of transmissive zones to be determined.

Existing data regarding the spatial extent and hydrologic properties of the hydrogeologic units at Yucca Mountain are sufficient to allow preliminary definition of flow properties (Czarnecki and Waddell, 1984; Czarnecki, 1985; and Montazer and Wilson, 1984). Computer models and simple mathematical calculations can then be used to determine the range of likely flow conditions. As more data are collected and more sophisticated hydrologic computer models are developed during site characterization, the range that encompasses possible flow conditions will be narrowed. Statistical methods will be used to determine the sensitivity of estimates of hydrologic flow conditions to the uncertainty in data and models. Conclusions about the hydrologic system of Yucca Mountain can then be derived by either of the following two approaches:

1. Using a set of reasonably conservative properties in the analyses (i.e., by using values from each end of the uncertainty range to derive the shortest flow time or the greatest flow volume).

2. Statistically sampling from the expected distribution of values for each property to develop a probability distribution for net flow conditions.

When considered together, these two approaches will provide increased confidence about the possible range and the most likely conditions for the hydrologic system at Yucca Mountain.

The degree to which uncertainty in the hydrologic models for Yucca Mountain must be reduced depends on whether the uncertainty jeopardizes confidence in the ability of the site to meet performance standards. Hydrologic tests planned for site characterization will greatly improve the confidence that can be placed in models of the Yucca Mountain site; they will provide important data for the validation of hydrologic models. Although the site cannot be readily characterized as defined by this favorable condition, a sufficient data base will be obtained during site characterization to allow the hydrologic system of Yucca Mountain to be modeled with reasonable certainty.

Conclusion

Detailed geologic mapping and drilling at Yucca Mountain and in its vicinity have demonstrated that the stratigraphic and structural features of Yucca Mountain are complex, but site characterization is expected to provide the data needed to model the site with reasonable certainty. The ground-water flow at Yucca Mountain from the land surface to the repository, from the repository to the water table, and laterally from the water table to the accessible environment can be characterized and modeled by techniques that establish reasonable bounds on critical hydrologic parameters. However, data currently available do not allow the site to be readily characterized and modeled with reasonable certainty. Therefore, the evidence indicates that this favorable condition is not present at Yucca Mountain.

(4) For disposal in the saturated zone, at least one of the following pre-waste-emplacement conditions exists:

    (i) A host rock and immediately surrounding geohydrologic units with low hydraulic conductivities.

    (ii) A downward or predominantly horizontal hydraulic gradient in the host rock and in the immediately surrounding geohydrologic units.

    (iii) A low hydraulic gradient in and between the host rock and the immediately surrounding geohydrologic units.

    (iv) High effective porosity together with low hydraulic conductivity in rock units along paths of likely radionuclide travel between the host rock and the accessible environment.

Conclusion

This condition does not apply to Yucca Mountain because disposal will not occur in the saturated zone.

(5) For disposal in the unsaturated zone, at least one of the following pre-waste-emplacement conditions exists:

    (i) A low and nearly constant degree of saturation in the host rock and in the immediately surrounding geohydrologic units.

    (ii) A water table sufficiently below the underground facility such that the fully saturated voids continuous with the water table do not encounter the host rock.

    (iii) A geohydrologic unit above the host rock that would divert the downward infiltration of water beyond the limits of the emplaced waste.

    (iv) A host rock that provides for free drainage.

    (v) A climatic regime in which the average annual historical precipitation is a small fraction of the average annual potential evapotranspiration.

Evaluation for the degree of saturation in the host rock

Information concerning the in situ distribution of moisture in the unsaturated formations at Yucca Mountain is available from various boreholes (Palaz, 1985; Montazer et al., 1985; Montazer and Wilson, 1984; and Weeks and Wilson, 1984). Results indicate that saturation in the Topopah Spring welded unit is quite variable. For example, in 44 samples reported by Montazer and Wilson (1984), saturation ranged from 40 to 90 percent, with a mean of about 65 percent and a standard deviation of about 20 percent. The wide variability is partly the result of measurement errors caused by the low porosity of the unit. In addition, in rocks with low porosity, slight variation in

pore size and water content causes relatively large variation in percent saturation.

Evaluation for the extent of fully saturated voids

The water table is 500 to 750 meters (1,600 to 2,500 feet) below the land surface (Robison, 1984), and 200 to 400 meters (656 to 1,300 feet) below the repository horizon. The zone of continuous, fully saturated voids is not expected to extend above the top of the Calico Hills nonwelded unit (Montazer and Wilson, 1984). The contrast between the fractured Topopah Spring welded unit and the porous Calico Hills nonwelded unit is likely to cause a capillary barrier that would retard upward flow from the pores of the Calico Hills nonwelded unit into the fractures of the Topopah Spring welded unit. Water could move into the matrix of the Topopah Spring welded unit, but only at an extremely low rate because of the low permeability. Measurements of the degree of saturation for the matrix of the Topopah Spring welded unit (mean of 65 percent, standard deviation of 20 percent) indicate that the pores of the host rock are not continuous, fully saturated voids (Montazer and Wilson, 1984).

Evaluation for the diversion of infiltration

Conditions exist at Yucca Mountain that are believed to promote unsaturated lateral flow that diverts downward infiltration of water. These conditions include the presence of dipping anisotropic units of contrasting properties (Montazer and Wilson, 1984). Under these conditions, a horizontal gravitational component of the potential gradient can be induced along the contacts between layers, resulting in down-dip flow even at very low saturations. Dips of the upper units are 3 to 8° to the east (USGS, 1984), and the overall lateral hydraulic conductivity of the Paintbrush nonwelded unit is much greater than the vertical hydraulic conductivity of this unit (Montazer and Wilson, 1984). The result is that more than 100 millimeters (4 inches) of lateral flux can be transmitted per year, assuming uniform lateral distribution of matric potential (Montazer and Wilson, 1984).

The potential for lateral flow at Yucca Mountain is enhanced by the presence of alternating nonwelded units and welded units. The contrasting properties of these two types of units can result in the formation of capillary and permeability barriers. The Paintbrush nonwelded unit, which overlies the Topopah Spring welded unit, is highly porous and relatively unfractured (Montazer and Wilson, 1984; Scott et al., 1983). The Topopah Spring welded unit, on the other hand, is highly fractured and has an extremely low matrix permeability (Montazer and Wilson, 1984). The contrasts between these two hydrogeologic units are expected to create capillary and permeability barriers that retard the downward flow of water from the matrix of the Paintbrush nonwelded unit into the Topopah Spring welded unit. A capillary barrier probably is formed between the matrix of the Paintbrush nonwelded unit and the fractures of the Topopah Spring welded unit. This barrier would form where water-filled pores in the nonwelded unit are smaller than the apertures of fractures in the underlying welded unit. Furthermore, the low matrix permeability of the Topopah Spring welded unit restricts the downward movement of water into the matrix of this unit.

8 0 0 0 8

0 6 6 0

Barriers may also exist at the upper contact of the Paintbrush nonwelded unit. The Tiva Canyon welded unit, which overlies this nonwelded unit and crops out at the surface, is highly fractured and transmissive. Its bulk permeability is estimated to be as much as a 3,000 times the bulk permeability of the underlying nonwelded unit. According to current conceptual models, during a major infiltration event recharging water would readily percolate down the fractures of the Tiva Canyon welded unit. If the event were intense and short lived, water that reached the upper boundary of the Paintbrush nonwelded unit would tend to move down dip at this boundary. This down dip flow would occur because of the initial difference in the permeability of the two units and because the pulse of water would temporarily trap air in the upper part of the nonwelded unit, thereby significantly decreasing the effective permeability to water. This lateral movement at the upper boundary would continue until structural features with high permeability were encountered.

The effectiveness of these conditions in actually causing lateral flow at Yucca Mountain is not known. Flux estimates are not definitive, but indicate that flux above the Topopah Spring welded unit probably is greater than within the unit in the primary repository area (Montazer and Wilson, 1984; see also discussion, Section 6.3.1.1.5).

Postulated lateral flow would move down dip until reaching structural features that have sufficient permeability to divert the flow. It is not yet established whether features such as the Ghost Dance fault and the fault zones that bound the primary repository area are such features. If such highly permeable features exist, they could serve as conduits for downward flow through the unsaturated section. However, percolating water cannot be conclusively demonstrated to be diverted beyond the limits of the emplaced waste as required by this subcondition, because the Ghost Dance fault, which occurs within the primary repository area, may act as one of these conduits.

Evaluation for free drainage

Free drainage of the host rock is considered to be a favorable condition because such a condition would allow water to move rapidly through the unit, thus minimizing potential contact time with waste disposal containers. The Topopah Spring welded unit is considered to be freely draining because its permeable fracture network would allow rapid flow if flux were to increase sufficiently to cause fracture flow.

The free-drainage characteristics of the Topopah Spring welded unit can be inferred from the pervasive and abundant fractures and the hydraulic properties of the unit. Welded units have relatively more abundant fractures (15 to 40 fractures per cubic meter) than the nonwelded units (as few as 1 fracture per cubic meter) in the subsurface at Yucca Mountain, which results in large bulk permeability. Thordarson (1983) reported a hydraulic conductivity of 1 meter (3.28 feet) per day for the Topopah Spring Member at Well J-13, where this unit occurs in the saturated zone. This hydraulic conductivity must be derived mostly from fractures; average saturated matrix hydraulic conductivity for the Topopah Spring welded unit, based on analyses of 31 core samples, is 0.722 millimeter (0.03 inch) per year or 1.97×10^{-6} meter (6.1×10^{-7} foot) per day (see Table 6-17 in Section 6.3.1.1.5). The high bulk permeability in the unsaturated zone is also reflected in the

extensive loss of drilling fluid in the Topopah Spring Member during the drilling of geologic core holes at Yucca Mountain (Spengler et al., 1981).

Rock-mass permeabilities to air have been determined for the unsaturated Topopah Spring welded unit to a depth of about 100 meters (328 feet) below the land surface (Montazer et al., 1985). Preliminary results show that this unit has permeabilities to air of 1×10^{-7} to 7×10^{-9} square centimeters (approximately equivalent to saturated hydraulic conductivities of 0.6 to 10 meters per day). Permeabilities in this range must be dominated by fractures because measurements of saturated matrix hydraulic conductivities are on the order of 1 millimeter (0.04 inch) per year. Similar conditions are expected deeper in the Topopah Spring welded unit, on the basis of preliminary data from drill hole USW UZ-1 and known high fracture frequencies (Scott et al., 1983). The ratio of permeabilities to air and water for unsaturated rocks indirectly indicates the potential for drainage.

The fractured, welded tuff of the host rock is known from drill-hole data to be continuous beneath the site (USGS, 1984); thus, free drainage conditions within this unit are expected throughout. However, it should be noted that some fractures are likely to be impermeable because of secondary mineral precipitation in the fracture openings. According to the conceptual model of Montazer and Wilson (1984), lateral flow may occur along the top of the Calico Hills nonwelded unit, possibly resulting in perching near major faults, at the base of the Topopah Spring welded unit. However, such an occurrence would be below the repository horizon, and therefore, would not affect free drainage through the repository.

No perched water was observed in the one unsaturated zone borehole (USW UZ-6) that has been drilled within the primary repository area and that penetrated the full section of the Topopah Spring welded unit (Whitfield, 1985). This borehole, located on Yucca Ridge, was drilled using a vacuum reverse-air-circulation drilling method, one that would permit ready identification of perched zones if encountered. Future investigations will evaluate the possible occurrence of perched water at the base of the unit near the Ghost Dance fault.

Perched water may have been observed in two boreholes adjacent to the primary repository area. These boreholes (USW UZ-1 and USW H-1) are located in Drill Hole Wash, in a hydrogeologic setting where perched water might be expected, according to the current hydrologic model of Yucca Mountain. Water sampled from the bottom of USW UZ-1 (at 387 meters (1,270 feet)) in the Topopah Spring welded unit) contained hydrocarbons similar to those in polymers used in the drilling fluid for USW G-1 about 305 meters (1,000 feet) away (Henderson and Benson, 1983; Whitfield, 1985). Thus, the water is believed to contain drilling fluid from USW G-1, but no determination was made that naturally occurring water also was present.

By means of a downhole television camera, small water seeps were observed entering the well bore of USW H-1 from fractures in the Topopah Spring Member (Rush et al., 1984). This well was drilled with a drilling fluid of air foam, consisting of detergent and water and large volumes of air; about 2.2 million liters (5.8×10^5 gallons) of water was used during drilling (Rush et al., 1984). No samples of the water seeping into the hole

were obtained, and it could not be determined whether the water was drilling fluid or perched water (Rush et al., 1984).

Evaluation for climatic regime

The meteorological recording stations at Yucca Mountain have not been operational long enough to yield historically significant precipitation records. Such records do exist, however, for several stations in the region (Bowen and Egami, 1983; Quiring, 1983). The annual average precipitation at Yucca Flat, 40 kilometers (25 miles) northeast of Yucca Mountain is 145 millimeters (5.7 inches); at Beatty, 26 kilometers (16 miles) to the west of Yucca Mountain, the annual average precipitation is 114 millimeters (4.5 inches). Precipitation at Yucca Mountain probably is slightly higher than that at Yucca Flat or Beatty, because of the terrain and the higher elevation. Average precipitation was estimated to be 150 millimeters (5.9 inches) per year for an area approximately equivalent to the primary repository area, which has an altitude range from about 1,200 to 1,465 meters (3,940 to 4,805 feet) (Montazer and Wilson, 1984, using information from Quiring, 1983).

Potential evapotranspiration was estimated by an empirical method reviewed in Rosenberg (1974) that uses a yearly heat index and mean monthly temperatures (the Thornthwaite method). Potential evapotranspiration for Yucca Mountain, corrected for actual sunshine hours, is about 630 millimeters (24.8 inches) per year. Therefore, the average annual precipitation, about 150 millimeters (5 to 6 inches), is about 20 percent of the annual potential evapotranspiration.

It should not be inferred from this condition that all precipitation at Yucca Mountain is evaporated. Intense summer storms and melting of winter snows undoubtedly result in pulses of infiltration that reach depths that are beyond the effects of evapotranspiration (i.e., net infiltration, or recharge, occurs).

Conclusion

The host rock and the immediately surrounding hydrogeologic units are not characterized by a low and nearly constant degree of saturation. The host rock is 200 meters (656 feet) or more above the water table and completely above the zone of continuous fully saturated voids. The Paintbrush nonwelded unit, about 30 meters (100 feet) thick, overlies the Topopah Spring welded unit and will probably serve as a buffer to divert pulses of water, but not necessarily beyond the limits of emplaced waste. The highly fractured host rock would provide free drainage if fracture flow were to occur. Precipitation is estimated to be less than 20 percent of potential evapotranspiration. Therefore, the evidence indicates that three of the five favorable conditions for disposal in the unsaturated zone are present at Yucca Mountain.

(1) Expected changes in geohydrologic conditions--such as changes
in the hydraulic gradient, the hydraulic conductivity, the effec-
tive porosity, and the ground-water flux through the host rock and
the surrounding geohydrologic units--sufficient to significantly
increase the transport of radionuclides to the accessible
environment as compared with pre-waste-emplacement conditions.

Geohydrologic conditions can be affected by both construction-induced
and naturally occurring processes. Construction-induced changes generally
would be confined to a small volume of rock in the immediate vicinity of the
repository and its shafts. Such changes are discussed further under the
guideline for rock characteristics (Section 6.3.1.3).

Natural changes in geohydrologic conditions may occur either in the
immediate vicinity of the repository or at greater distances from the
repository. The changes that might be expected include (1) changes in the
rate of ground-water recharge caused by climatic changes, (2) increased
hydraulic conductivity or changes in the spatial relationships among
hydrogeologic units caused by tectonic movement, (3) changes in the effective
porosity caused by an increase in the number of fractures or by an increase
or decrease in their apertures, and (4) changes in the vertical distance to
the zone of saturation and, therefore, in the estimated radionuclide
transport time to the accessible environment.

Evaluation for climatic changes

Major global climatic fluctuations probably will occur within the next
100,000 years, according to current knowledge of the dynamics of climate and
the geologic and climatic records of past changes. The causes of climatic
changes include increases in the global atmospheric concentration of carbon
dioxide and changes in the earth's orbit. The possible climatic effects of
these changes (Spaulding, 1983; Spaulding et al., 1984) are summarized below.

A substantial increase in carbon dioxide in the atmosphere would
increase the radiative heating of the earth's surface and result in the
melting of the Antarctic ice cap (Kukla and Gavin, 1981; Etkins and Epstein,
1982). The subsequent rise in sea level would not directly affect the Yucca
Mountain site, but temperatures could increase by 3°C (5°F) or more, and
summer rainfall would increase.

The configuration of the earth's orbit partly controls the solar
radiation received by the earth, and changes in the precession, obliquity, or
eccentricity of the orbit may be the principal causes of ice ages (Imbrie and
Imbrie, 1980). If so, orbital changes would continue to influence the
cooling trend of the last 6,000 years, with a glacial stage resulting in
about 23,000 years and a glacial maximum, similar in magnitude to that of the
late Wisconsin maximum (about 18,000 years ago) resulting in about 60,000
years. A return to pluvial climates would mean an increase in effective
moisture, but valley floors would remain semiarid. The annual precipitation
could be assumed to be as much as 100 percent higher than that at present.
The mean annual temperature would be 6 to 7°C (11 to 13°F) lower than that at
present (Spaulding et al., 1984).

The effects of a return to pluvial climatic conditions include the likelihood of increased recharge at Yucca Mountain. Associated with the increased recharge could be increased unsaturated zone flux and fracture flow; increased water-table altitude; modified and shortened unsaturated zone flow paths; and modified saturated zone flow paths, hydraulic gradients, and ground-water velocities.

The amount of increased recharge that would occur under a return to pluvial conditions is highly uncertain and would depend upon a variety of interrelated factors. These factors include not only the amount of increase in average annual precipitation, but the seasonal distribution and type of precipitation; the amount and rate of snowmelt; and changes in evapotranspiration, runoff characteristics, and soil and plant cover. Czarnecki (1985) estimated that, for an assumed 100 percent increase in precipitation (based on Spaulding et al., 1984), the ground-water recharge rate would be about 15 times the modern-day recharge rate. See Section 6.3.1.4.3 for a discussion of uncertainties in this recharge estimate. The estimate was made by applying the empirical technique of Eakin et al. (1951), and it does not take into account the factors listed above; therefore, it principally provides an indication that recharge increases could be greater than precipitation increases. The impacts of the increased recharge on the distribution and nature of flux in the unsaturated zone are unknown. Fracture flow may occur in the Topopah Spring welded unit, but the continued effectiveness of lateral flow and capillary and permeability barriers in maintaining low flux through the host rock is unknown.

Increased recharge probably would result in an increased altitude of the water table. Using the conservative increase in recharge rate of 15 times the modern value and other conservative assumptions, Czarnecki (1985) simulated a water-table rise of about 130 meters (427 feet) (Section 6.3.1.4) beneath Yucca Mountain. This amount would not result in inundation of the repository, but much of the Calico Hills nonwelded unit would become saturated. Flow velocities and pathways in this unit would change because of the change from unsaturated to saturated conditions, which would result in increased hydraulic conductivity and effective porosity and decreased hydraulic gradient.

The computer simulations of Czarnecki (1985) indicated that, as a result of increased recharge, changes in the direction of ground-water flow at and near the primary repository area would be small, but vertically integrated flux vectors would have a more southerly component. Saturated zone flux magnitude would increase 2 to 4 times near the primary repository area, resulting in decreased ground-water travel times to the accessible environment. The simulations also showed that ground-water discharge areas would occur upgradient from their present locations, but they still would be beyond the accessible environment boundary and, thus, would not necessarily affect the transport of radionuclides to the accessible environment.

No evidence has been found for modern or Quaternary springs or seeps on the flanks of Yucca Mountain, despite many detailed field investigations at the site. Potential spring deposits of calcite, silica, and sepiolite associated with faults have been observed in trenches in the immediate

vicinity of Yucca Mountain. Preliminary conclusions are that these deposits formed at or near surface temperatures, and that there is no evidence to indicate an origin different from the pedogenic process that resulted in similar mineral assemblages in sand ramps near the site (Vaniman et al., 1985).

Water from any future springs or seeps that might develop on the flanks of Yucca Mountain during periods of increased recharge would not pass through the repository, because the flow would be perched and the repository would be at a lower elevation than such springs. Water moving through the repository would enter the saturated ground-water system locally and travel toward the regional discharge areas.

Evaluation of effects of changes in water-table altitude

A discussion of the potential effects of changes in the position of the water table on transport of radionuclides to the accessible environment is presented in Section 6.3.1.4.4. Assuming that the water table rises to its maximum pluvial position, matrix diffusion and other retardation mechanisms are expected to delay the transport of radionuclides to the accessible environment so that U.S. Environmental Protection Agency release limits would not be exceeded (see sections 6.3.1.2.3 and 6.3.1.4.4).

Evaluation of effects of tectonic movement

The Basin and Range Province is tectonically active and is characterized by earthquakes and past volcanic activity (Section 6.3.1.7). Faults of Quaternary age occur near Yucca Mountain (Swadley et al., 1984). Future fault movement is shown in Section 6.3.1.7.5 to be unlikely to significantly affect the geohydrologic system at Yucca Mountain. The rate of tectonic activity is also likely to be slow enough that displacement of hydrogeologic units over the next 10,000 years is expected to be insignificant.

The primary repository area is relatively free from faulting as compared with the surrounding areas; however, the host rock is a densely welded tuff, and the frequency of fractures is expected to be high. The unsaturated host rock is free draining, and an increase in the number of fractures caused by renewed faulting generally would not be detrimental. Movement along a fault cutting the repository is not likely to have a significant effect on the flux of water through the host rock, which would be expected to remain quite low. However, if new faults penetrated units above the host rock, additional water may be intercepted and transmitted into the host rock if the fault zone was more permeable than surrounding rock matrix. Any effect on the rate of waste dissolution would be slight because of the overall low flux.

Tectonic movement at Yucca Mountain could result in an increase in the number of fractures in the Calico Hills nonwelded unit. However, an increase in fracturing within this unit probably would have no effect on flow unless major new faults develop that could act as flow pathways. The matrix hydraulic conductivity of the vitric Calico Hills unit generally is high enough for it to transmit all the flux that enters from the matrix of the overlying Topopah Spring welded unit. This is assuming the upper bound on current flux estimates of 0.5 millimeter (0.02 inch) per year (Wilson, 1985). For the zeolitic Calico Hills, fracture flow is likely to occur in portions

with saturated hydraulic conductivity values of about 0.5 millimeter (0.02 inch) per year and less.

Even in the saturated zone, fracture flow probably is not significant in the tuffaceous beds of Calico Hills. Observations in drill holes indicate that this unit is generally less fractured than welded tuffs in the section. In addition, hydraulic data for the tuffaceous beds of Calico Hills within the saturated zone at Well J-13 indicate that fracture permeability is 0.094 to 0.15 meters (3.7 to 5.9 inches) per day, which is moderate (Thordarson, 1983). At Well UE-25b#1, the unit is more permeable (Lahoud et al., 1984); this site is in Drill Hole Wash, where fractures not typical of most of Yucca Mountain could account for the higher permeability. In the units below the tuffaceous beds of Calico Hills, an increase in fracture frequency would have little effect on flow rates. Drill-hole data indicate that most of the flow occurs within fractures, which are already quite common in the moderately to densely welded tuffs. The resulting small increase in hydraulic conductivity probably would not be significant.

Potential changes in effective porosity due to tectonic movement probably would have a negligible effect on the transport of radionuclides to the accessible environment. In the saturated tuffs where fracture flow is dominant, a decrease in effective porosity would be accompanied by a larger decrease in hydraulic conductivity because effective porosity is a function of aperture size, whereas conductivity is a function of the square of the aperture size. In the unsaturated zone, an increase in effective porosity could occur as a result of fracture formation, which probably would increase the ability of the host rock to freely drain excess water, a favorable characteristic. In the saturated zone, effective porosity could increase by fracture formation or decrease by mineral precipitation. On the other hand, the effect of a decrease in effective porosity by precipitation of minerals in fractures may be offset by increased sorption due to fracture coatings that are often very reactive minerals (zeolites, smectites, and manganese oxides) and may increase retardation of radionuclides.

Conclusion

Substantial changes in geohydrologic conditions may result from possible changes in climatic conditions. Tectonic movements are expected to have minor effects on flow conditions. No changes in geohydrologic conditions are expected that would significantly increase the transport of radionuclides to the accessible environment as compared with pre-waste-emplacement conditions because retardation mechanisms are likely to remain effective. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(2) The presence of ground-water sources, suitable for crop irrigation or human consumption without treatment, along ground-water flow paths from the host rock to the accessible environment.

Evaluation

Ground-water sources suitable for human consumption are present along probable flow paths from the repository generally to the south or southeast

toward Jackass Flats and the Amargosa Desert (Waddell, 1982; Robison, 1984). Possible ground-water sources along those flow paths are defined in the guidelines as "aquifers that have been or could be economically and technologically developed as sources of water in the foreseeable future." Ground water withdrawn from the Yucca Mountain area, for example, from wells J-12 and J-13, has been used as drilling water for exploratory holes at and near the Nevada Test Site (NTS) and for other minor domestic uses on the NTS. The water extracted has not been used for irrigation.

Beneath Yucca Mountain, the water-resource potential is low compared with other areas in the vicinity of the NTS (Sinnock and Fernandez, 1982) because people do not normally drill for water from the top of a mountain, especially when the depth to the water table is much less in nearby valleys. On the flats on the east side of Yucca Mountain (Fortymile Wash and western Jackass Flats), the potential is considered to be higher. However, everywhere within the controlled area, the depth to water is more than 400 meters (1,300 feet) and pumping water for irrigation from such depths is likely to be uneconomical.

From the standpoint of the commercial value of ground water, irrigation is not of major concern in the site area primarily because of the poor characteristics of the alluvium, which make the site undesirable for agricultural use. The alluvium is coarse grained and drains rapidly except in the playa areas, where the concentration of salts makes it unlikely that crops could be grown. Pressure to develop ground water locally for human consumption is not likely, because land use is restricted. Even if extensive ground-water extraction caused the water table to be lowered, this would result in a thicker unsaturated zone, which would increase the travel time to the accessible environment.

Conclusion

Ground-water sources suitable for crop irrigation and human consumption are present at Yucca Mountain along ground-water flow paths between the host rock and the accessible environment. However, because of the great depths to ground water and topographic conditions, the ground-water resource potential is small compared with that in nearby areas, such as the Amargosa Desert. Nonetheless, the statement of the potentially adverse condition refers to the presence of ground water, not to the likelihood of its use. The evidence therefore indicates that this potentially adverse condition is present at Yucca Mountain.

(3) The presence in the geologic setting of stratigraphic or structural features--such as dikes, sills, faults, shear zones, folds, dissolution effects, or brine pockets--if their presence could significantly contribute to the difficulty of characterizing or modeling the geohydrologic system.

Evaluation

The available reports and conclusions about the general complexity of the Yucca Mountain area are discussed under favorable condition 3 of this section.

The geologic characteristics of the surface at Yucca Mountain are well known from detailed mapping (see Figure 6-20, in Section 6.3.1.7) (Scott and Bonk, 1984). Because of the numerous drill holes and interpretations of geophysical data, it is unlikely that major unrecognized features exist in the subsurface. Locations and displacements of normal faults can be estimated with reasonable certainty (Bath and Jahren. 1984). Zones with small displacement occur north of the primary repository area; the high hydraulic gradient in the area where they occur (Robison, 1984) indicates that the permeability along these zones is probably low, except for along the lower part of Drill Hole Wash. Many holes have been drilled in or near Drill Hole Wash to characterize the zone. Small basaltic dikes have been observed on the flank of Yucca Mountain northwest of the primary repository area; they may extend into the primary area and may produce the magnetic anomalies observed by Bath and Jahren (1984).

Conclusion

As a result of extensive field mapping and geophysical studies, faults, fracture zones, and dikes are known to exist at and near the Yucca Mountain site. These features will not prevent the formulation of conceptual models for the geohydrologic system. However, their presence contributes to the difficulty of characterizing and modeling the geohydrologic system. Therefore, the evidence indicates that this potentially adverse condition is present at Yucca Mountain.

6.3.1.1.5   Disqualifying condition

A site shall be disqualified if the pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment is expected to be less than 1,000 years along any pathway of likely and significant radionuclide travel.

Evaluation

The time required for water to travel from the repository to the accessible environment depends on the hydraulic properties of the formations through which the water will flow, the hydrologic conditions, and the lengths of flow paths. The flow path of interest at Yucca Mountain includes segments in both the unsaturated and the saturated zones, as shown in the hydrogeologic section in Figure 6-2. The rocks at Yucca Mountain consist mainly of ash-flow tuff, bedded tuff, and lava that extend to depths greater than 1,829 meters (6,000 feet). Depths to the water table range from 500 to 750 meters (1,600 to 2,500 feet) below the land surface (Robison, 1984). Figure 6-3 consists of a map of the Yucca Mountain site, showing contours of water-table altitudes and drill-hole locations. A summary of key characteristics and properties of stratigraphic and hydrogeologic units at Yucca Mountain is shown in Table 6-17.

A portion of the precipitation that falls on Yucca Mountain infiltrates below the land surface to become net infiltration. Net infiltration is the infiltrating water that does not remain in shallow storage or is not rapidly returned to the atmosphere via evapotranspiration, but rather moves downward
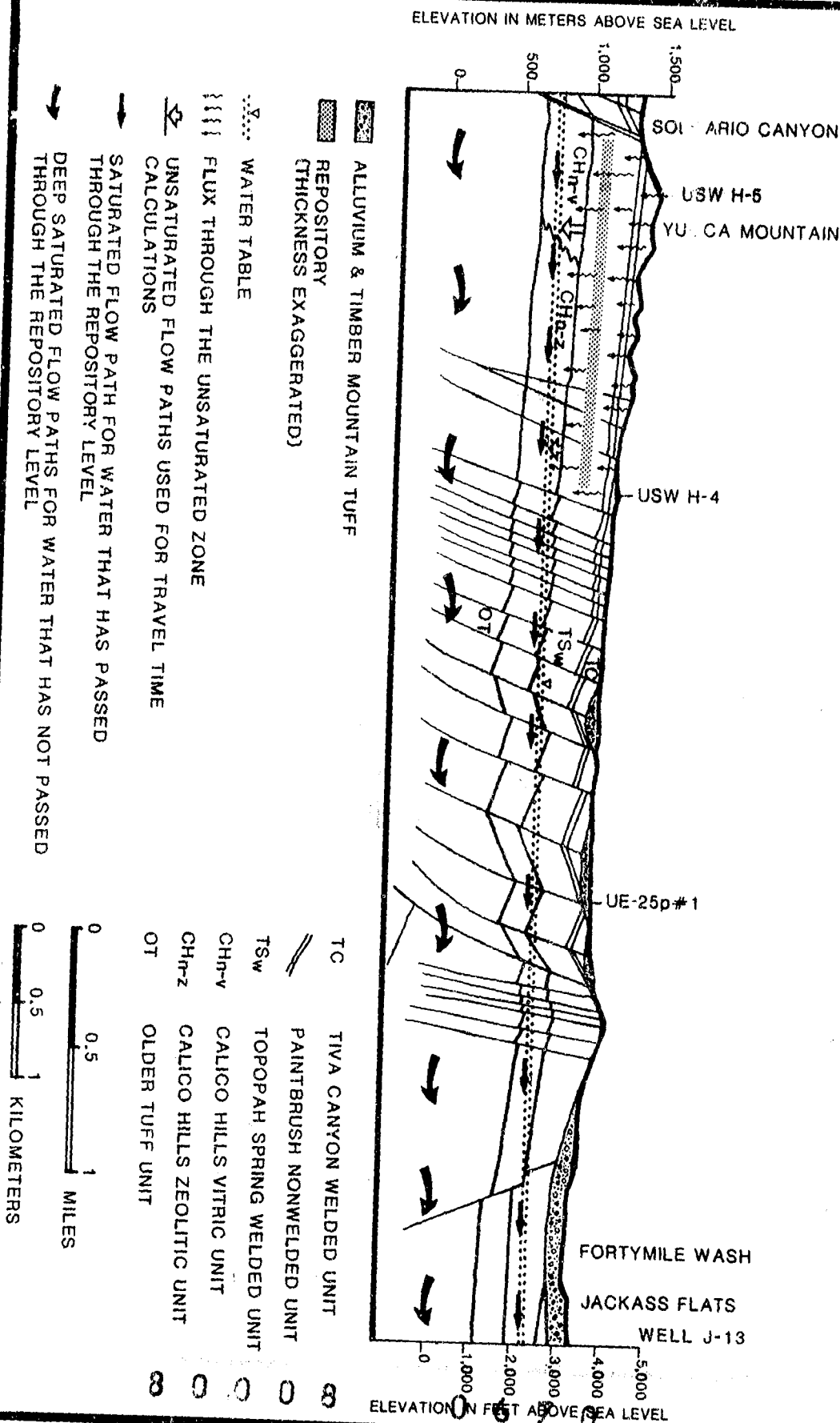
Figure 6-2. Conceptual hydrogeologic section from Solitario Canyon, northwest of the site, to Well J-13 in Jackass Flats. The unsaturated zone is above the water table; the saturated zone is below the water table. Modified from Scott and Bonk (1984).

ELEVATION IN METERS ABOVE SEA LEVEL

1,500
1,000
500
0

SOLITARIO CANYON
USW H-5
YUCCA MOUNTAIN
CHn-v
CHn-z
USW H-4
OT
TSw
UE-25p#1
FORTYMILE WASH
JACKASS FLATS
WELL J-13

ELEVATION IN FEET ABOVE SEA LEVEL
5,000
4,000
3,000
2,000
1,000
0

ALLUVIUM & TIMBER MOUNTAIN TUFF

REPOSITORY (THICKNESS EXAGGERATED)

WATER TABLE

FLUX THROUGH THE UNSATURATED ZONE

UNSATURATED FLOW PATHS USED FOR TRAVEL TIME CALCULATIONS

SATURATED FLOW PATH FOR WATER THAT HAS PASSED THROUGH THE REPOSITORY LEVEL

SATURATED FLOW PATH FOR WATER THAT HAS NOT PASSED THROUGH THE REPOSITORY LEVEL

DEEP SATURATED FLOW PATHS FOR WATER THAT HAS NOT PASSED THROUGH THE REPOSITORY LEVEL

TC   TIVA CANYON WELDED UNIT
        PAINTBRUSH NONWELDED UNIT
TSw   TOPOPAH SPRING WELDED UNIT
CHn-v   CALICO HILLS VITRIC UNIT
CHn-z   CALICO HILLS ZEOLITIC UNIT
OT   OLDER TUFF UNIT

0   0.5   1   KILOMETERS
0   0.5   1   MILES

Figure 6-3. Water-table position at Yucca Mountain showing 20-meter contours of water-table altitude, location of drill holes, outlines of the primary repository area (dashed), and perimeter drift of the design repository (solid). Modified from Sinnock et al. (1986).

Table 6-17. Dual classification of Tertiary volcanic rocks at Yucca Mountain; stratigraphic units reflect origin and hydrogeologic units reflect hydrologic properties[a]

STRATIGRAPHIC UNIT		TUFF LITHOLOGY[b]	HYDROGEOLOGIC UNIT[c]	SATURATED MATRIX HYDRAULIC CONDUCTIVITY	COMMENTS
Alluvium		– – –	Alluvium	Generally high	Underlies wash; thin layer on flats
Paintbrush Tuff	Tiva Canyon Member	MD	Tiva Canyon welded unit	1 mm/yr	Caprock that dips 5-10° eastward at Yucca Mountain. High fracture density
	Yucca Mountain Member	NP, B	Paintbrush nonwelded unit	3300 mm/yr	Vitric, nonwelded, porous, poorly indurated, bedded in part. Low fracture density.
	Pah Canyon Member				
	Topopah Spring Member	MD	Topopah Spring welded unit	0.7 mm/yr[d]	Densely to moderately welded; several lithophysal cavity zones. intensely fractured. Central and lower part is potential host rock for repository. Bulk hydraulic conductivity in saturated zone east of the site (at well J-13) about 1.0 m/day.
Tuffaceous beds of Calico Hills		NP, B	Calico Hills nonwelded unit (Vitric Devitrified (in part zeolitic))	Vitric: 107 mm/yr[d] / Zeolitic 0.5 mm/yr[d]	Beneath Yucca Mountain, base of units for un-saturated zone determined by water table. Calico Hills nonwelded unit is vitric in southwest Yucca Mountain, zeolitic in east and north. Zeolitic boundary generally parallels the water table with vitric units above and zeolitic units below a transitional boundary.
Crater Flat Tuff	Prow Pass Member	MD	PP_w	88 mm/yr[d]	
		NP, B	PP_n	22 mm/yr[d]	
	Bullfrog Member	MD	BF_w	118 mm/yr[d]	
		NP, B	BF_n (Crater Flat Member)	22 mm/yr[d]	
	Tram Member			22 mm/yr	None
Lava			Undifferentiated	Very low	Occurs in northwest part of repository block.
Lithic Ridge Tuff				Very low	None
Older volcanics				Very low	In USW H-1 hydraulic head about 50 m higher than water table.
Pre-Tertiary Rocks				Unknown	Occurs 2.5 km east of proposed repository at depth of 1250 m in UE-25p#1, where hydraulic head is about 20 m higher than water table. Bulk hydraulic conductivity high, probably due to high fracture density

[a] Data from Montazer and Wilson (1984) except as indicated.

[b] NP = nonwelded to partially welded; MD = moderately to densely welded; B = bedded.

[c] Hydrogeologic unit symbols: PP_w = Prow Pass welded unit; PP_n = Prow Pass nonwelded unit; BF_w = Bullfrog welded unit; BF_n = Bullfrog nonwelded unit.

[d] Data from Sandia National Laboratories Tuff Data Base (SNL, 1985).

into the deeper parts of the unsaturated zone. Flux at any depth, also referred to as percolation, is determined by the volume and the rate of net infiltration and by the hydraulic properties of rocks in the unsaturated zone. Upon reaching the water table beneath Yucca Mountain, percolating water becomes recharge and joins other ground water in transit from sources of recharge north or northwest of Yucca Mountain. The ground water then moves generally horizontally to the accessible environment, driven by a hydraulic gradient approximately equal to the slope of the water table and controlled by the hydraulic properties of the intervening rocks.

A discussion of the rationale used to derive a value for unsaturated zone flux at Yucca Mountain is presented below, followed by a description of the model that was used to calculate travel time in the unsaturated zone. This model uses a range of values for effective porosity and saturated matrix hydraulic conductivity to produce a distribution of travel times for a given value of flux. A final section provides the calculation of travel time in the saturated zone, so that the total travel time from the disturbed zone to the accessible environment can be determined.

Unsaturated zone flux

The flux needed for the travel-time calculations for this evaluation is the percolation rate (flux) between the disturbed zone and the water table. The primary repository area has a surface expression and also represents the outline of the conceptual repository at depth (Figure 6-3). The primary repository area occupies only a part of the physiographic feature called Yucca Mountain. The northern half and southern tip of Yucca Mountain and the fault zone that bounds the area along the eastern side are not a part of the primary repository area. Recharge beneath the primary repository area probably is less than recharge beneath Yucca Mountain as a whole. This difference occurs because (1) lateral flow probably occurs above the repository horizon and diverts some water beyond the repository area to be recharged along the eastern fault zone; and (2) much of the recharge at Yucca Mountain probably results from precipitation falling on parts of the mountain where altitudes are greater than those of the surface expression of the primary repository area. If these conditions exist, then the use of the estimate of recharge (0.5 millimeter (0.02 inch) per year) occurring beneath all of Yucca Mountain for unsaturated zone travel-time calculations beneath the primary repository area is a conservative approach (i.e., the calculated travel times would be shorter than those that would be predicted from a more realistic value of flux). In order to evaluate the appropriateness and degree of conservatism of this value, estimates and comparisons were made of various flux parameters at Yucca Mountain, using two approaches (Wilson, 1985).

The first approach to estimate deep flux within and below the repository was to analyze various lines of field and laboratory evidence (Wilson, 1985). Weeks and Wilson (1984) estimated a matrix flux of 0.2 millimeter (7.9 x 10^{-3} inch) per year in the Topopah Spring welded unit, using matrix properties of core. Montazer and Wilson (1984) estimate from 10^{-7} to 0.2 millimeter (3.9 x 10^{-9} to 7.9 x 10^{-3} inch) per year of flux could be occurring in the matrix of the Topopah Spring welded unit. This range of values is based principally on analyses of thermal flux, properties of cores, and in situ potential gradients. Montazer et al. (1985) indicate that an upper bound of

0.5 millimeters (0.02 inch) per year is consistent with the available information. Preliminary analyses of geothermal gradients indicate that an upward component of vapor flux probably exists in the fractures of the Topopah Spring welded unit (Montazer and Wilson, 1984; Montazer et al., 1985). Although no firm value for moisture flux in the Topopah Spring unit has yet been established, all preliminary field and laboratory estimates are less than 0.5 millimeter (0.02 inch) per year.

The second approach (Wilson, 1985) was to estimate ground-water recharge at Yucca Mountain by applying a technique developed by Maxey and Eakin (1949) and described further by Eakin et al. (1951). The technique provides a method for estimating ground-water recharge in basins in Nevada on the basis of relationships that were established among altitude, precipitation, and the percentage of precipitation that infiltrates to become recharge. The relationships were established by equating basin recharge to ground-water discharge for basins where this parameter could be estimated. For large areas, net infiltration and recharge can be considered to be approximately equivalent. Although infiltration occurs sporadically in an arid environment, such as exists at Yucca Mountain, average annual net infiltration probably is an appropriate input parameter for simulating flux conditions at the substantial depths of the repository horizon and below. As noted by Weeks and Wilson (1984), in unsaturated zones that are hundreds of meters thick, the large near-surface fluctuations in soil-moisture tension that result from episodic infiltration events followed by evapotranspiration become totally damped at depth, and deep percolation becomes nearly constant with time. According to the conceptual model for Yucca Mountain developed by Montazer and Wilson (1984), relatively large pulses of infiltrating water probably are transmitted through the Tiva Canyon welded unit but are damped in the Paintbrush nonwelded unit by means of lateral flow or changes in saturation, and are transmitted as steady-state flux through the potential host rock, the Topopah Spring welded unit.

The Eakin method was applied by Rush (1970) to estimate average annual recharge for basins in the Nevada Test Site area, including western Jackass Flats and Crater Flat. These basins have Yucca Mountain as a mutual boundary and include some areas where altitudes exceed 1,829 meters (6,000 feet). Rush (1970) estimated an average annual recharge of 1.4 millimeters (0.055 inch) per year for Jackass Flats and 0.6 millimeter (0.024 inch) per year for Crater Flat. Czarnecki (1985) applied Rush's (1970) results to a smaller area that included Yucca Mountain but excluded altitudes greater than 1,829 meters (6,000 feet). Czarnecki (1985) calculated a value of 0.7 millimeter (0.027 inch) per year for recharge beneath the smaller area; he adjusted this value to 0.5 millimeter (0.02 inch) per year. In Czarnecki's (1985) analysis, almost all of the recharge was derived from precipitation falling on an altitude zone that is about 305 meters (1,000 feet) higher, on the average, than that of the surface area above the repository (altitude 1,220 to 1,524 meters (4,000 to 5,000 feet)). Thus, only a small part of the 0.7 millimeter (0.027 inch) per year recharge would be expected to come from precipitation falling on the surface above the primary repository area. The value calculated by Czarnecki (1985) is probably greater than the actual value of ground-water recharge beneath the primary repository area at Yucca Mountain. The surface above the primary repository area is not transected by any major washes originating at higher altitudes that could transfer runoff

downstream to be recharged beneath the repository. Furthermore, the washes that extend downward from the ridges within the surface area above the repository may be effective in carrying runoff that might otherwise become recharge to locations beyond this area. This is apparent in that runoff from major precipitation events is periodically carried away by Fortymile Wash. Thus, considering the altitude zone of the surface of the primary repository area and the uncertainty in the Eakin method, recharge is probably less than 0.5 millimeter (0.02 inch) per year according to Czarnecki (1985).

Although the method described by Eakin et al. (1951) has been widely used to estimate ground-water recharge in basins in Nevada and Utah, the technique provides only an approximation of recharge, and it was not intended for site-specific application. Czarnecki (1985) described some of the limitations: local variations in topographic slope and aspect are ignored, rock lithology and vegetation type and density are only indirectly included, and drainage channels are treated the same as other areas. General hydrologic equilibrium is assumed to exist for the flow system, a condition that may not prevail where thick unsaturated zones and long flow paths may result in a substantial lag time between net infiltration, recharge, and discharge. Furthermore, the method does not specify where recharge occurs; runoff that crosses altitude zones can result in recharge in areas different from those where the precipitation fell. The result is that predicted values of recharge may be too small or too large, depending on whether runoff enters or leaves the area. Despite these limitations, Watson et al. (1976), in an evaluation of the method, concluded that it is the only practical method available for estimating recharge in Nevada from data that now exist.

An indirect test of the Maxey-Eakin method also confirms that the estimate of 0.5 millimeter (0.02 inch) per year for recharge at Yucca Mountain probably is both reasonable and conservative (Wilson, 1985). Recharge rates as a percentage of average annual precipitation for arid and semiarid areas worldwide were compared to recharge estimates obtained by applying the Maxey-Eakin method (Wilson, 1985). Although there are numerous sources of uncertainty in the recharge estimates, recharge rates for many of the areas are less than predicted by the Maxey-Eakin method. Especially significant are five areas where recharge is estimated to be less than 0.5 percent of precipitation. Each of these areas receives precipitation that is greater than the 150 millimeters (5.9 inches) per year at Yucca Mountain, and recharge as a percentage of precipitation varies from 0 to 0.12 percent. These worldwide data appear to support the conservatism of the recharge estimate of 0.3 percent of 150 millimeters (5.9 inches) per year, or 0.5 millimeter (0.02 inch) per year for Yucca Mountain. Field and laboratory investigations planned for site characterization are intended to provide further confidence in the estimate of recharge beneath the primary repository area at Yucca Mountain.

In conclusion, various lines of reasoning and evidence demonstrate that 0.5 millimeter (0.02 inch) per year is a conservative value of flux to use in calculating unsaturated zone pre-waste-emplacement travel time. Field and laboratory evidence and assessments of the precipitation-recharge relationship for the primary repository area indicate that the unsaturated zone flux below the repository horizon is less than 0.5 millimeter (0.02 inch) per year (Wilson, 1985). For this reason a value of 0.5 millimeter (0.02 inch) per year is used in the calculations of ground-water travel time and in several

other calculations reported in this environmental assessment. It is considered to represent the upper bound to the estimated range of current flux below the repository horizon. Investigations conducted during site characterization will further define unsaturated zone flux.

Calculation of unsaturated zone travel times

Because the thicknesses and hydraulic properties of the hydrogeologic units that make up the unsaturated zone at Yucca Mountain are variable, an approach was developed to take this variability into account in calculation of travel times (Sinnock et al., 1986). The disturbed zone was assumed to extend to a position 50 meters (164 feet) below the midplane of the repository. A projection of the perimeter drift of the design repository (see Figure 6-3) on the surface of the disturbed zone was divided into 963 columns, extending to the water table. Total unsaturated zone thickness and the thicknesses of hydrogeologic units between the disturbed zone and the water table are shown in Figure 6-4. The travel time to the water table through each of the 963 vertical columns was determined. The total travel-time distribution for a given value of moisture flux will be presented as a contour map, a histogram, and a cumulative-frequency diagram of travel times. Table 6-18 shows the values for hydraulic parameters used for these calculations, including means and standard deviations for effective porosity and saturated matrix hydraulic conductivity for the seven hydrogeologic units considered in this calculation.

As summarized above, the three-dimensional volume of each hydrogeologic unit beneath the repository area was subdivided into 963, 76.2-meter (250-foot) square vertical columns, with each column enclosing 5,806 square meters (62,500 square feet) (Sinnock et al., 1986). Each column was divided into 3.05-meter (10-foot) thick elements, giving a three-dimensional grid of the site composed of 80,521 elements, 10 feet thick and 250 feet on each side. See Figure 6-5 for a schematic drawing of the columns and elements used in the model. The particle velocity for each element within a particular hydrogeologic unit was calculated by using a value of saturated matrix hydraulic conductivity that was obtained by standard statistical sampling methods from the frequency distribution that best describes the conductivity data for that particular unit. This randomly selected value of conductivity was compared with the value of flux. If the flux value was less than 0.95 times the saturated matrix hydraulic conductivity, it was assumed that the flow within that element was entirely in the porous rock matrix, and a value of matrix effective porosity was then chosen by random sampling from the frequency distribution of porosity values for the appropriate hydrogeologic unit. The water particle velocity for each element was then calculated by dividing the flux value by the sampled effective porosity, assuming a hydraulic gradient equal to 1.0. The velocity was modified, according to concepts explained by Brooks and Corey (1966), to account for the relation between effective flow area and saturation (see Table 6-18 for the formula used to calculate particle velocities).

The value of 0.95 was used for the comparison of the flux value with saturated conductivity to account for potential initiation of fracture flow at saturations less than 100 percent (Sinnock et al., 1986). If the ratio of flux to the randomly sampled value of saturated matrix hydraulic conductivity was equal to or greater than 0.95, it was assumed that fracture flow occurred
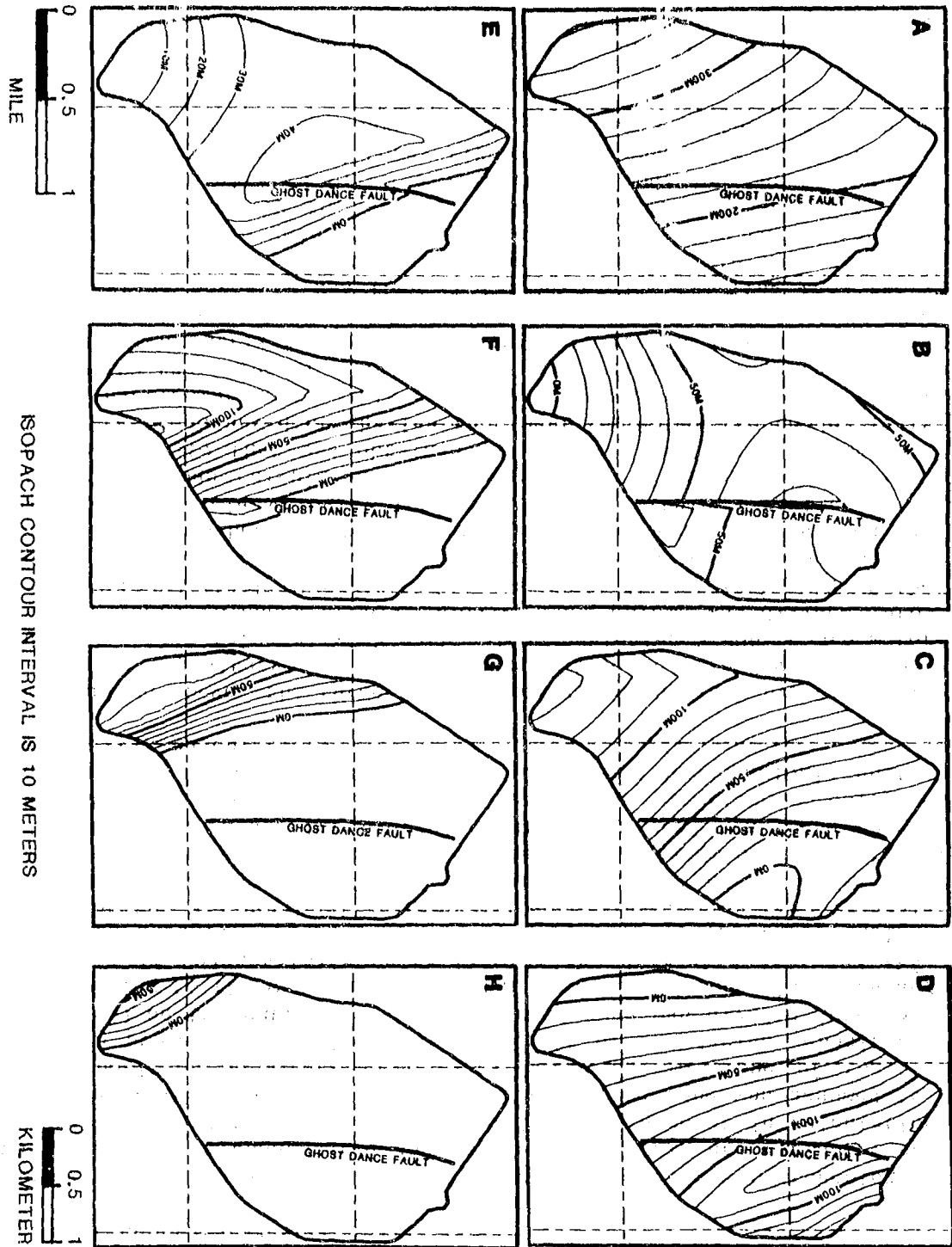
Figure 5-4. Isopach contour maps: (A) Total thickness from disturbed zone to the water table; (B) Thickness of undisturbed Topopah Spring welded unit, TS_w; (C) Thickness of the Calico Hills vitric unit, CH_v; (D) Thickness of the Calico Hills zeolitic unit CH_{n-z}; (E) Thickness of the Prow Pass welded unit, PP_w; (F) Thickness of the Prow Pass nonwelded unit, PP_n; (G) Thickness of the Bullfrog welded unit, BF_w; and (H) Thickness of the Bullfrog nonwelded unit, BF_n. Modified from Sinnock et al.

Table 6-18. Parameters used in travel-time calculations for the unsaturated zone

Parameter / Hydrogeologic unit[a]	TS_w	CH_{n-v}	CH_{n-z}	PP_w	PP_n	BF_w	BF_n[b]	Remarks
Hydraulic gradient (i)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	$i = \partial h/\partial l = \partial \psi/\partial l + \partial z/\partial l$ where $l = x,y,z,$ $\partial \psi/\partial l \ll 1.0$ and $\partial z/\partial l = \partial z/\partial z = 1.0$, i.e. vertical gravity flow is assumed.
Mean saturated-matrix hydraulic conductivity K_s (mm/yr)[c]	0.7 (31)	107 (8)	0.5 (31)	88 (10)	22 (7)	118 (2)	22 (NA)	$K_s = \ln^{-1}(\text{mean}[\ln(K_s)])$ Values in parentheses are the number of measurements.
$K_s - 1\sigma$ (mm/yr)	0.1	1.9	0.0	29	3	58	3	$\pm 1\sigma(K_s) = K_s \div \ln^{-1}(\ln\sigma[K_s])$
$K_s + 1\sigma$ (mm/yr)	4.1	6,090	7.6	261	142	240	142	
Mean Effective Porosity $\overline{n}_e \pm 1\sigma$	0.11 $\pm.05$ (138, 12)	0.32 $\pm.09$ (23, 6)	0.27 $\pm.05$ (65, 10)	0.24 $\pm.06$ (27, 4)	0.25 $\pm.06$ (75, 2)	0.22 $\pm.09$ (120, 2)	0.25 $\pm.06$ (NA)	$\overline{n}_e = n_b(1-S_r)$, where n_b is the mean bulk, dry porosity and S_r is residual saturation. Ordered pairs in parentheses are number of measurements of n_b and S_r, respectively.
Range of thicknesses (m)[d]	0-72 (98.5)	0-135 (95.3)	0-133 (94.5)	0-44 (83.2)	0-122 (63.1)	0-91 (25.6)	0-55 (7.5)	Thicknesses between disturbed zone and water table for area within the design repository boundaries. Values in parentheses are percentages of total repository are underlain by the units.
Particle velocity, V (mm/yr) — $q = 0.5$ mm/yr	5.0	5.5	1.9	7.6	4.1	7.3	4.1	$V = (q/n_e)(q/K_s)^{-1/\epsilon}$, where n_e and k_s are mean values and q is flux.
Particle velocity, V (mm/yr) — $q = 1.0$ mm/yr	8.9 (2,780)	9.4	3.4 (4,650)	12.8	7.2	12.5	7.2	Values in parentheses indicate fracture-flow velocity calculated as $(q-K_s)/0.0001$, where 0.0001 is the assumed effective porosity of fractures.
ϵ[e]	5.9	4.2	7.0	4.0	5.2	4.6	5.2	Empirical constant that represents the effects of the relationship between pore-size distribution and saturation on the amount of the effective porosity, n_e, available for flow; the effect of ϵ is to reduce flow area and thus increase particle velocity relative to values calculated using q/n_e.

[a] TS_w = Topopah Spring welded unit; CH_{n-v} = Calico Hills vitric unit; CH_{n-z} = Calico Hills zeolitic unit; PP_w = Prow Pass welded unit; PP_n = Prow Pass nonwelded unit; BF_w = Bullfrog welded unit; BF_n = Bullfrog nonwelded unit.

[b] Assumed to be hydrologically identical to PP_n.

[c] Saturated conductivity and effective-porosity data are from Sandia National Laboratories Tuff Data Base (SNL, 1985).

[d] Range of thickness, Sandia National Laboratories Interactive Graphics Information System (IGIS) (SNL, 1985).

[e] Values calculated from data in Peters et al. (1984).
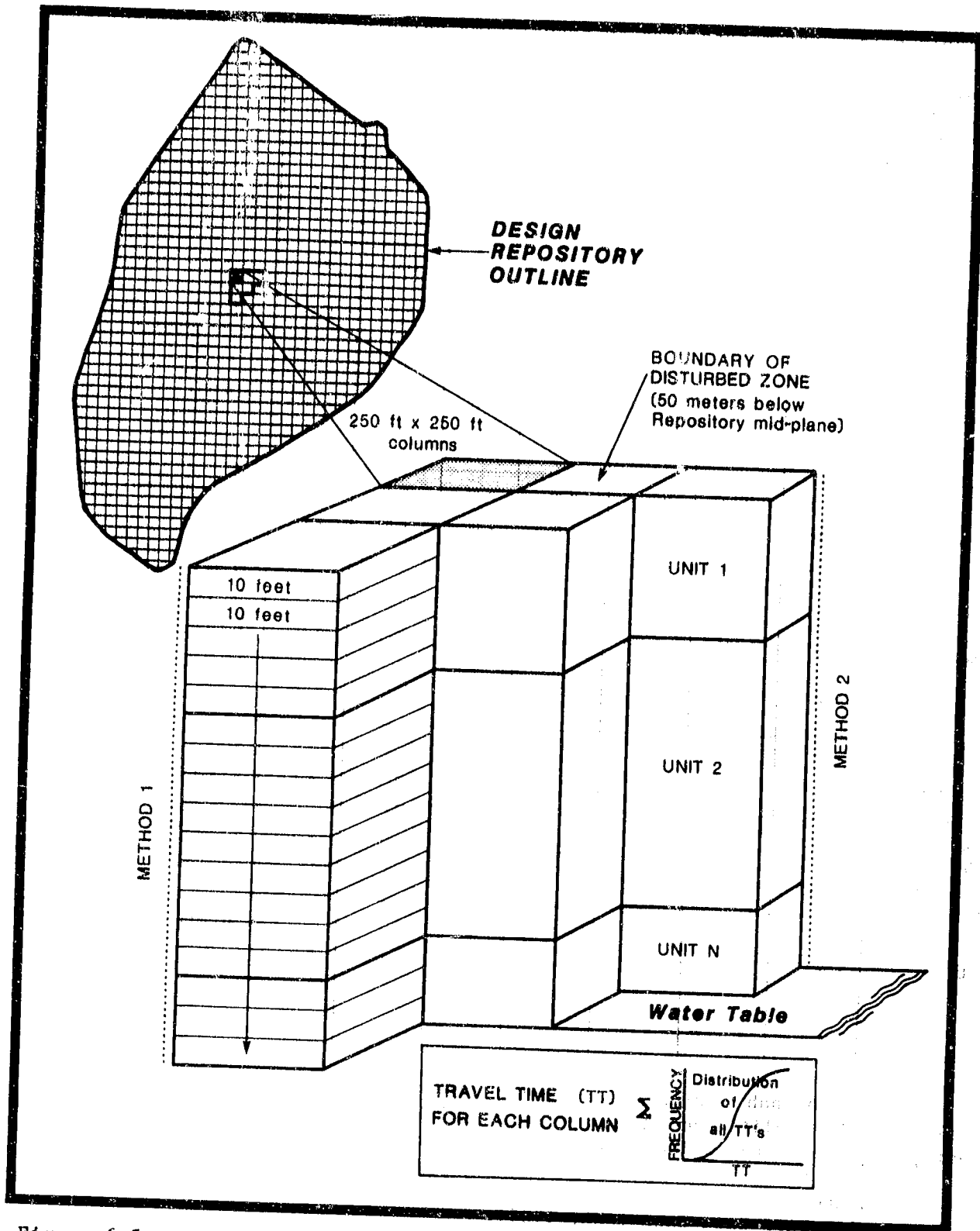
Figure 6-5. Schematic diagram illustrating three-dimensional geometry for multiple elements 10 feet thick. In Method 2, only 1 element is assigned to each unit and its thickness equals the unit thickness. Modified from Sinnock et al. (1986).

for that quantity of flux in excess of the value of saturated matrix conductivity (or in excess of 0.95 times conductivity when the ratio of flux to hydraulic conductivity is between 1.0 and 0.95). An effective porosity of 0.0001 was assumed for all fracture flow, and the velocity of flow in fractures for each element was determined by dividing the calculated value of flux in the fractures by 0.0001. The portion of flux remaining in the matrix was used to obtain a matrix-flow time as well as a fracture-flow time for each element characterized by fracture flow. Matrix-flow times for these dual porosity elements were usually greater than the fracture-flow times; however, the shorter of matrix or fracture flow time was used to generate the travel-time distribution through these elements.

This procedure was repeated for each 10-foot thick element within each of the 963 vertical columns for each hydrogeologic unit occurring between the disturbed zone and the water table (Sinnock et al., 1986). The sum of all individual-element travel times represents a value of travel time along one column. This procedure was repeated 10 times for each column to provide a representation of the variation in travel time due to the variation in hydraulic parameters. Reflecting the varying thicknesses shown in figures 6-4(B) through 6-4(H), each column is composed of differing thicknesses of the various unsaturated zone hydrogeologic units. These differences produce a source of variation in travel time in addition to the variation caused by random sampling of parameters. It was determined that differences in thickness of hydrogeologic units have a greater influence on the modeled travel times than the variations due to use of randomly selected values for hydraulic parameters.

Results for the upper bound on estimated flux of 0.5 millimeter (0.02 inch) per year are shown in figures 6-6 and 6-7. Figure 6-6 shows smoothed contours of travel time in 5,000-year intervals from the disturbed zone to the water table. This travel-time contour map clearly shows a gradient from the shorter travel times of less than 20,000 years on the east, to travel times greater than 60,000 years on the south. Note that this pattern correlates well with the thicknesses of major hydrogeologic units shown in figures 6-4(B) through 6-4(H). Figure 6-7 shows a histogram of travel times for the 10 realizations for each of the 963 columns. Cumulative-frequency curves are also provided in Figure 6-7 illustrating how travel times within each hydrogeologic unit contribute to the distribution of total travel times. The minimum travel time is estimated to be 9,345 years, with a mean travel time of 43,265 years and a maximum of 80,095 years (Sinnock et al., 1986). It should be noted that minimum and maximum travel-time values cannot be observed on the histogram because of the intervals used to construct the histogram. However, the above values were obtained from the output used to plot the histogram.

Several major assumptions underlie the calculations presented in this section. The first assumption is that unsaturated zone flux below the disturbed zone is vertical and uniformly distributed in time and space (i.e., the unsaturated zone at Yucca Mountain is assumed to have a vertical hydraulic gradient determined solely by gravity). The hydrologic properties of the rocks above the repository are probably able to dampen episodic infiltration so that nearly steady-state flow occurs between the repository and the water table. An assumption of a vertical hydraulic gradient of unity is probably conservative because the occurrence of lateral flow would reduce
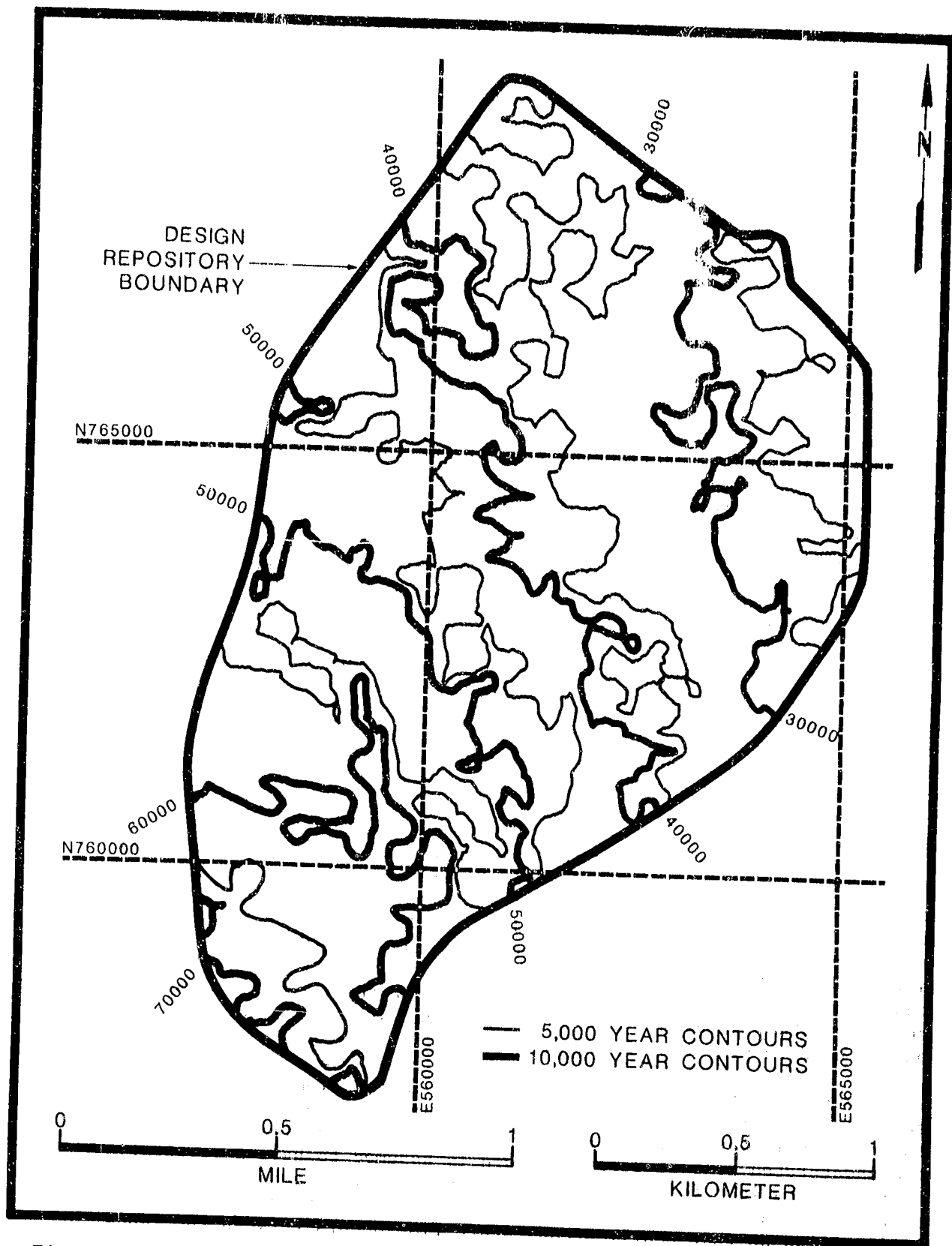
Figure 6-6. Travel-time contour map from disturbed zone to water table.
Modified from Sinnock et al. (1986).
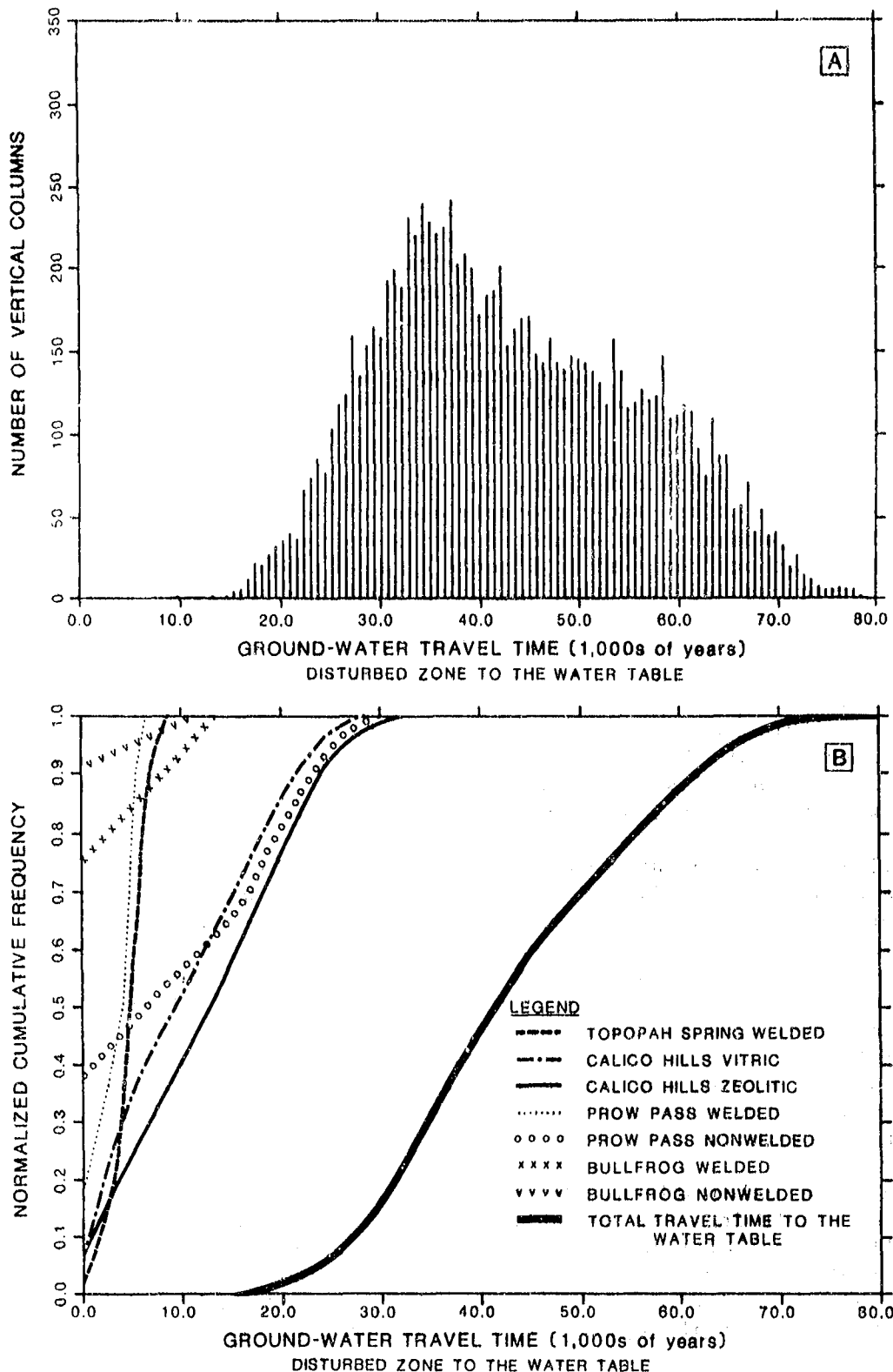
Figure 6-7. Travel-time plots: (A) Travel-time histogram for
9,630 realizations of travel-time model; flux = 0.5 millimeter
(0.02 inch) per year; element thickness = 10 feet;
(B) Cumulative frequency of travel times for 9,630 realizations
(normalized to a scale of 0.0 to 1.0). Modified from Sinnock et
al. (1986).

this value to less than one, thereby decreasing the particle velocity. Only in the case of diversion to a zone of higher permeability would this assumption be nonconservative.

A second major assumption is that the effective hydraulic conductivity through the matrix of any given rock volume delicately adjusts by changes in saturation so that the effective conductivity exactly equals the flux. This assumption is particularly important where the value of conductivity is less than the flux. In these cases, the matrix is assumed to conduct water up to an amount equal to the saturated conductivity, while the remainder of the flux travels in fractures. If the flux is less than the saturated conductivity for a particular interval, the relations among pore sizes, saturations, and capillary pressures are assumed to adjust to yield an effective conductivity just sufficient to pass the flux under a gravity-controlled gradient.

A third assumption underlying these calculations is that, at certain conditions of saturation, water probably does not move rapidly through fractures until flux approaches the saturated matrix hydraulic conductivity. Concepts from other authors reviewed in Sinnock et al. (1984) support this assumption. These references indicate that negative capillary pressures exerted by the pores of the matrix are sufficiently strong to rapidly draw water away from fractures (where pressures are much less negative) even when the matrix is nearly saturated. This capillary-driven advection probably precludes significant, sustainable fracture flow where the conductivity is less than the flux within the unsaturated tuffs beneath the repository. Some flow may take place in thin layers along the walls of fractures under unsaturated conditions. Such flow would, however, be likely to have the same properties as flow in the matrix (Montazer and Wilson, 1984).

All evidence indicates that flux is less than 0.5 millimeter (0.02 inch) per year (Wilson, 1985). Nevertheless, travel time was also calculated for a flux of 1.0 millimeter (0.04 inch) per year, or twice the upper bound flux of 0.5 millimeter per year (0.02 inch per year) (Sinnock et al., 1986). A total travel-time histogram is shown in Figure 6-8. Even for this unrealistically conservative estimate of flux, the data plotted on this histogram show a minimum travel time in the unsaturated zone of at least 3,700 years, a mean travel time of 21,045 years, and a maximum of 45,190 years. Results of these calculations provide confidence that the 1,000-year travel time required by the disqualifying condition would be satisfied even with a flux that is much larger than expected.

In these calculations, the values of conductivity and the method of sampling result in a low probability that fracture flow will be identified for all vertical elements in a single column from the disturbed zone to the water table. Similarly, both rapid and very slow matrix flow, calculated from random sampling of effective porosity, are extremely unlikely to occur throughout a vertical column. To examine sampling effects that may be due simply to the sampling method, an alternative approach, shown as Method 2 in Figure 6-5, was implemented whereby one value of conductivity and effective porosity chosen by random sampling was used for the entire thickness of each hydrogeologic unit (Sinnock et al., 1986). To generate probabilities of flow times, the sampling was repeated 100 times for each column. This approach yields higher, but probably physically unrealistic, estimates of the
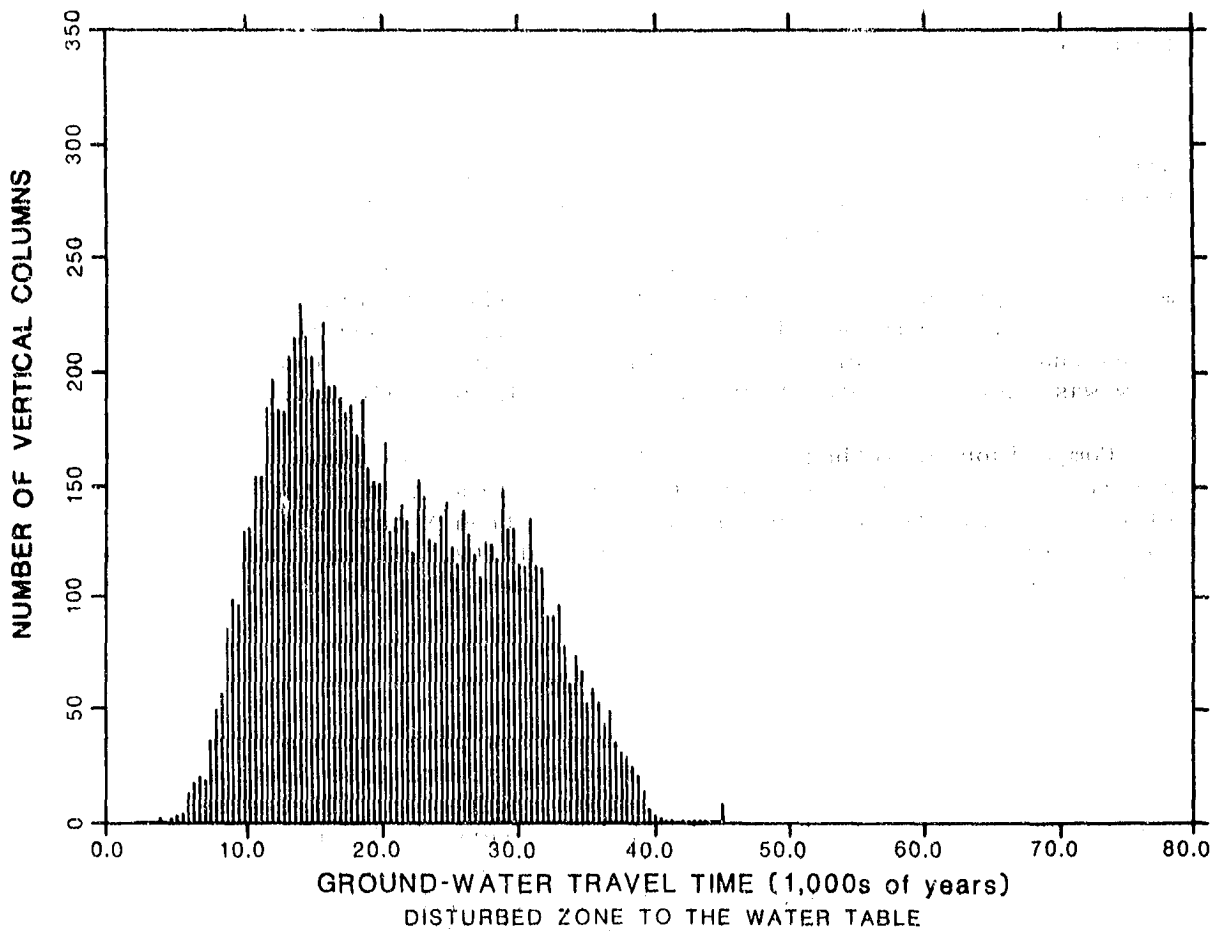
Figure 6-8. Travel-time histogram for 9,630 realizations of the travel-time model; flux = 1.0 millimeter (0.04 inch) per year; element thickness = 10 feet. Modified from Sinnock et al. (1986).

probability of continuous fracture flow and rapid matrix flow than the 10-foot interval sampling method described above, which more realistically accounts for vertical as well as horizontal variation in the sampling parameters.

The cumulative frequency curves generated by the two sampling methods for a flux of 0.5 millimeter (0.02 inch) per year are compared in Figure 6-9. Although the overly conservative method (i.e., Method 2: single value per hydrogeologic unit) predicts travel times of less than 1,000 years for the 0.5 millimeter (0.02 inch) flux value, this probability is less than 2 percent (Sinnock et al., 1986). The results from this highly conservative modeling approach are included to indicate the potential effect of variations in hydrologic parameters in the vertical direction and to acknowledge travel times that could occur in the highly improbable situation in which fracture flow was sustained throughout an entire hydrogeologic unit.

Comparison of methods 1 and 2 (Figure 6-9) also shows that as more physical realism is introduced into the travel-time model, the range of travel times is likely to be compressed. Moving from Method 2 to Method 1 clearly had the effect of removing the low-probability, extreme values in the tails of the frequency distribution of travel times from the disturbed zone to the water table.

Calculation of saturated zone travel time

For the saturated zone, the assumed flow path extends from the eastern edge of the primary repository area southeastward (see Section 3.3.2.1) for 5 kilometers (3 miles) to the accessible environment (Figure 6-3). Approximately 80 percent of this path (4 kilometers (2.4 miles)) is in the tuffaceous beds of the Calico Hills, and the remainder of the flow path (1 kilometer (0.6 mile)) would be through the welded Topopah Spring Member or the welded Crater Flat Tuff (Prow Pass or Bullfrog member). Estimates for ground-water travel times along this travel path have been made using the following assumptions:

1. Darcian flow applies.

2. Flow paths are horizontal.

3. The water-level measurements shown in Figure 6-3 (based on Robison, 1984) provide a reasonable estimate for the hydraulic gradient along the flow path.

4. The system is isotropic within each unit, and hydraulic conductivity values obtained from hydraulic tests of wells in the southeastern Yucca Mountain area are representative of the values along the flow path.

5. Calculated effective fracture porosities from Sinnock et al. (1984) are reasonably conservative for flow in the saturated tuffaceous beds of the Calico Hills.

The average saturated hydraulic conductivity for the Calico Hills has been estimated to be 69 meters (230 feet) per year on the basis of values of
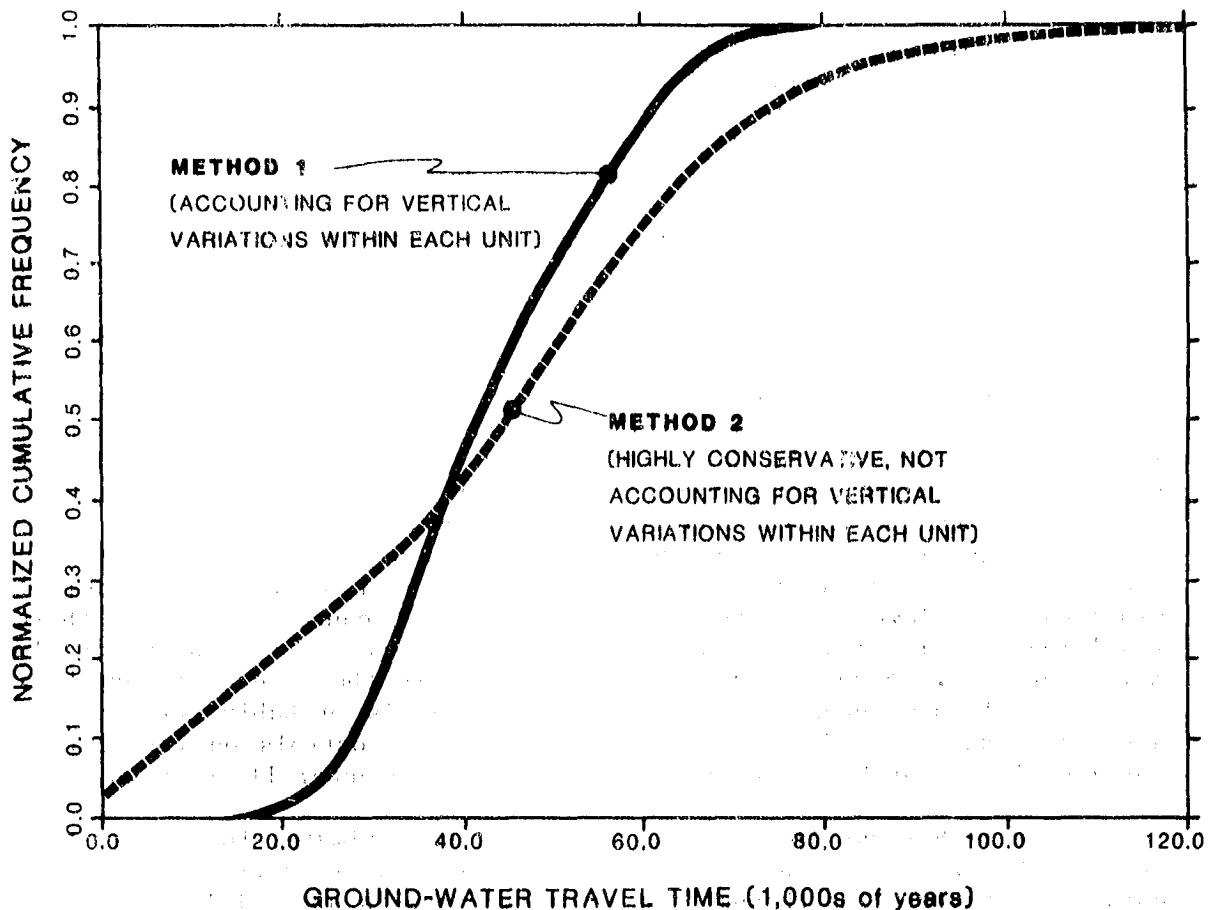
Figure 6-9. Cumulative frequency of travel times: Method 1—more realistic case; Method 2—more conservative, probably unrealistic, case. Flux is 0.5 millimeter (0.02 inch) per year for both cases. Modified from Sinnock et al. (1986).

0.26 meter (0.85 foot) per day from pumping tests in Well UE-25b#1 (Lahoud et al., 1984) and 0.12 meter (0.4 foot) per day from Well J-13 (Thordarson, 1983). The saturated hydraulic conductivity for the Topopah Spring Member is estimated to be 365 meters (1,198 feet) per year on the basis of 1.0 meter (3.28 feet) per day from Well J-13 (Thordarson, 1983).

On the basis of these assumptions, the hydraulic gradient has been estimated using water-level altitudes of 730.1 meters (2,395.3 feet) at USW H-4 and 728.1 meters (2,388.8 feet) at Well J-13 (Robison, 1984). The distance between these wells is approximately 6.1 kilometers (3.8 miles). The hydraulic gradient within each of the two units has been estimated from the two water-level altitudes, the two hydraulic conductivity values used, and the property of mass conservation, which requires that the amount of water flowing through the Calico Hills unit is the same as that flowing through the Tonopah Spring unit. Uncertainties in these estimates of hydraulic gradient include the following components: with very low gradients, small errors in the measurements can have significant effects on the value of the gradient; the measured water level at Well J-13 could be expected to be lower than the static water level because of pumping, thereby resulting in a steeper estimated gradient; and vertical components of flow may be present. Because vertical flow would have the effect of lengthening the flowpath, the assumption of horizontal flow is probably conservative, although Waddell et al. (1984) indicate that the controls on vertical and horizontal flow at Yucca Mountain are variable and generally unknown.

Table 6-19 shows these values and provides estimates for travel times through the two units mentioned above. On the basis of these estimates, the cumulative travel time through the saturated zone is about 141 years.

This estimate of travel time is considered to be conservative, based on the assumptions mentioned above and on the fracture effective porosities reported by Sinnock et al. (1984). These effective porosities were calculated by multiplying the fracture density from Scott et al. (1983) by the effective aperture (calculated from a relationship provided by Freeze and Cherry, 1979). The resulting effective porosities are considered to be reasonable estimates for fracture flow in the saturated zone. However, estimates of saturated effective porosity for both matrix and fracture flow range from 8 to 12 percent (Sinnock et al., 1984); 2.7 to 8.7 percent for the Topopah Spring Member (Thordarson, 1983); and 20 to 30 percent for the Calico Hills vitric unit (Sinnock et al., 1984). These effective porosities are more representative of the hydraulic conductivities indicated in Table 6-19, and in particular of the water-bearing nature of the Topopah Spring Member in the vicinity of Well J-13 (Thordarson, 1983). Use of more realistic values of effective porosity would be likely to lead to a saturated ground-water travel time at least ten times greater (i.e., approximately 1,000 years) than that indicated in Table 6-19. However, as no data exist to indicate that matrix flow predominates over fracture flow, the effective porosity used in this analysis assumes fracture flow in order to provide a conservative travel-time estimate.

Summary of travel times

A summary of total travel times is provided in Table 6-20 for the upper bound on flux of 0.5 millimeter (0.02 inch) per year. Adding the saturated

Table 6-19. Estimates for ground-water travel times through the saturated zone

Parameter	Unit	
	Calico Hills	Topopah Spring
Length of path (m)[a]	4,000	1,000
Hydraulic conductivity (m/yr)[b]	69	365
Hydraulic gradient[c]	4.6×10^{-4}	8.6×10^{-5}
Darcy velocity (m/yr)[d]	3.2×10^{-2}	3.1×10^{-2}
Calculated effective fracture porosity[e]	4×10^{-4}	2.8×10^{-3}
Particle velocity (m/yr)[f]	80	11
Travel time (yr)[g]	50	91

[a] 1 meter (m) = 3.281 feet
[b] Hydraulic conductivity for Calico Hills from Lahoud et al. (1984) and Thordarson (1983); Topopah Spring from Thordarson (1983).
[c] Based on water levels at wells USW H-4 and J-13 and conservation of mass.
[d] Darcy velocity = (hydraulic conductivity) x (hydraulic gradient).
[e] Data from Sinnock et al. (1984).
[f] Particle velocity = (Darcy velocity)/(bulk effective porosity).
[g] Travel time = (length of path)/(particle velocity).

zone travel time of about 140 years to the minimum, mean, and maximum unsaturated zone travel times produces total minimum, mean, and maximum travel times of about 9,485; 43,405; and 80,235 years.

Conclusion

Using an upper bound on the estimated unsaturated zone flux and a range of values for saturated hydraulic conductivity and effective porosity at the Yucca Mountain site, estimates of the expected pre-waste-emplacement ground-water travel time along any path of likely and significant radionuclide travel from the disturbed zone to the accessible environment are more than 1,000 years. Therefore, the evidence does not support a finding that the site is disqualified (level 1).

Travel paths	Travel times (years)
Unsaturated zone	
Minimum	9,345
Mean	43,265
Maximum	70,095
Saturated zone	
Calico Hills segment	50
Topopah Spring segment	91
Total travel time[a]	
Minimum	9,485
Mean	43,405
Maximum	80,235

[a]Total travel time is the total saturated zone travel time (rounded to the nearest 10 years) added to the minimum, mean, and maximum unsaturated zone travel time.

6.3.1.1.6 Evaluation and conclusion for the qualifying condition on the postclosure geohydrology guideline

Evaluation

The evaluation of the geohydrology disqualifying condition in the previous section shows that the ground-water travel time from the disturbed zone to the accessible environment for the upper bound on flux of 0.5 millimeter (0.02 inch) per year has a mean value of about 43,405 years, with a range of values from 9,485 years to 80,235 years.

Climatic changes during the Quaternary Period may have caused cyclic fluctuations in precipitation, infiltration, recharge, and water-table altitude beneath Yucca Mountain. Analyses presented in Section 6.3.1.2.3 establish the potential effectiveness of matrix diffusion as an agent for delaying the release of radionuclides to the accessible environment by factors of at least 100 and perhaps as much as 400. On the basis of these estimated retardation factors, Section 6.3.1.4.4 presents a discussion of the potential effects of climatic changes on radionuclide releases from a repository at the Yucca Mountain site. Considering conservative retardation factors and the maximum water-table rise that has been simulated for full pluvial conditions, radionuclide travel times from the repository to the accessible environment are expected to remain sufficiently long so that release limits could not be exceeded.

Although the Yucca Mountain site is considered complex from the standpoint of geologic structure and characterization of the unsaturated zone, methods are available to obtain all the information necessary for prediction of long-term site performance with reasonable certainty. Preliminary predictions of performance are available in the geochemistry and performance assessment sections of this environmental assessment. In favorable condition 4 in Section 6.3.1.2, both an experimental and a modeling approach are presented for estimating radionuclide releases from the engineered barrier system (EBS). For flux estimates that are twice the upper bound of 0.5 millimeter (0.02 inch) per year, releases estimated by either method are well within the EBS release limits of 1 part in 100,000 per year of the 1,000 year inventory. Section 6.4.2 presents preliminary estimates of cumulative radioactivity released to the accessible environment at 10,000 and 100,000 years after repository closure for a 0.5 millimeter (0.02 inch) per year flux. All cumulative radioactivity release values at 100,000 years after closure are below the cumulative releases permitted for 10,000 years after closure in 40 CFR Part 191 (1985), and cumulative releases at 10,000 years are essentially zero.

Conclusion

Quantitative analyses show that the expected radionuclide releases from the engineered barrier are less than 1 part in 100,000 (Section 6.3.1.2); they also show that the expected releases to the water table over the next 10,000 years would be essentially zero (Section 6.4.2). Analyses of ground-water flow time, ground-water flux, and radionuclide retardation further support the position that the characteristics of the Yucca Mountain site and the processes operating there permit, and probably ensure, compliance with the limits on radionuclide release to the accessible environment. Therefore, the evidence does not support a finding that the site is not likely to meet the qualifying condition for geohydrology (level 3).

6.3.1.1.7 Plans for site characterization

Various hydrologic tests are planned during site characterization, including tests during the construction and in situ phases of the exploratory shaft program at Yucca Mountain. Radial boreholes from the shaft will be used to determine vertical permeability and to evaluate the extent of mining-induced changes in vertical permeability near the shaft. Vertical flux and flux mechanisms, particularly across the boundaries of hydrogeologic units, will be evaluated by injection tests and continuous monitoring in boreholes. Samples of pore water will be dated and used to help evaluate the flow velocities and travel times through various units. Thermal logs will be used as another means for estimating the vertical movement of water in the unsaturated zone, which is important for confirming estimates of flux and travel times.

A bulk-permeability test will be conducted during the in situ phase of testing to establish the hydrologic characteristics of a larger volume of the host rock than can be sampled from a borehole. The results of this test will improve hydrologic models and allow comparisons with borehole and laboratory-scale measurements. Also planned is an infiltration test, designed to obtain

the hydraulic properties of the host rock, including permeability and flow characteristics, and to provide data for curves of hydraulic conductivity versus the matric potential.

Hydrologic testing of the unsaturated Calico Hills nonwelded unit, which underlies the host rock, is also planned. Determination of the transport properties and barrier characteristics of this unit will be extremely important in establishing its capacity for the retardation of radionuclides. Borehole testing of the saturated zone will be conducted to assist in evaluating conceptual models of ground-water flow and to determine probable flow paths and flow properties.

6.3.1.2 Geochemistry (10 CFR 960.4-2-2)

6.3.1.2.1 Introduction

The qualifying condition for this guideline is as follows:

The present and expected geochemical characteristics of a site shall be compatible with waste containment and isolation. Considering the likely chemical interactions among radionuclides, the host rock, and the ground water, the characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

The geochemistry technical guideline addresses the present and expected geochemical characteristics of the proposed Yucca Mountain site and provides the basis for demonstrating compatibility with performance objectives for waste containment and isolation as specified in the Nuclear Regulatory Commission and the U.S. Environmental Protection Agency technical criteria.

This guideline contains five favorable conditions, three potentially adverse conditions, and one qualifying condition. The evaluations reported below are summarized in Table 6-21.

6.3.1.2.2 Data relevant to the evaluation

Summary of available data

The mineral content, mineral composition, and petrographic texture of the rocks at and near Yucca Mountain have been determined from drill-core rock samples and bit cuttings (Heiken and Bevier, 1979; Sykes et al., 1979; Carroll et al., 1981; Bish et al., 1982; Caporuscio et al., 1982; Bryant and Vaniman, 1984; Levy, 1984a; and Vaniman et al., 1984). The mechanism and

Table 6-21. Summary of analyses for Section 6.3.1.2; geochemistry (10 CFR 960.4-2-2)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITIONS	
(1) The nature and rates of the geochemical processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.	The evidence indicates that this favorable condition is present at Yucca Mountain: sorptive minerals (zeolites) were present in the tuff at Yucca Mountain throughout the Quaternary time; they are still present and are expected to contribute to isolation over the next 100,000 years.
(2) Geochemical conditions that promote the precipitation, diffusion into the rock matrix, or sorption of radionuclides; inhibit the formation of particulates, colloids, inorganic complexes, or organic complexes that increase the mobility of radionuclides; or inhibit the transport of radionuclides by particulates, colloids, or complexes.	The evidence indicates that this favorable condition is present at Yucca Mountain: geochemical properties are expected to promote matrix diffusion; zeolites along flow paths will sorb radionuclides; organic complexes that would increase radionuclide mobility are not present; particulates and colloids may be filtered by tuffs, thereby inhibiting transport.
(3) Mineral assemblages that, when subjected to expected repository conditions, would remain unaltered or would alter to mineral assemblages with equal or increased capability to retard radionuclide transport.	The evidence indicates that this favorable condition is present at Yucca Mountain: the radionuclide-retardation capacity of tuffs is not expected to degrade because of repository conditions.
(4) A combination of expected geochemical conditions and a volumetric flow rate of water in the host rock that would allow less than 0.001 percent per year of the total radionuclide inventory in the repository at 1,000 years to be dissolved.	The evidence indicates that this favorable condition is present at Yucca Mountain: expected geochemical conditions and vertical flux of less than 0.5 millimeter (0.02 inch) per year are expected to limit release to less than 0.001 percent per year of total radionuclide inventory at 1,000 years after permanent closure.

Table 6-21. Summary of analyses for Section 6.3.1.2; geochemistry (10 CFR 960.4-2-2) (continued)

Condition	Department of Energy (DOE) finding
(5) Any combination of geochemical and physical retardation processes that would decrease the predicted peak cumulative releases of radio-nuclides to the accessible environment by a factor of 10 as compared to those predicted on the basis of ground-water travel time without such retardation.	The evidence indicates that this favorable condition is present at Yucca Mountain: chemical adsorption, low flux, and matrix diffusion are expected to limit radionuclide release by at least a factor of 10.

POTENTIALLY ADVERSE CONDITIONS

Condition	Department of Energy (DOE) finding
(1) Ground-water conditions in the host rock that could affect the solubility or the chemical reactivity of the engineered barrier system to the extent that expected repository per-formance could be compromised.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: the stainless steel waste disposal container and waste forms are not expected to show detrimental effects due to host-rock water chemistry.
(2) Geochemical processes or conditions that could reduce the sorption of radionuclides or degrade the rock strength.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: sorp-tive zeolites are metastable, but little reaction is expected in the next 100,000 years. Geochemical processes are too slow to affect repository perfor-mance through degradation of rock strength.
(3) Pre-waste-emplacement ground-water condi-tions in the host rock that are chemically oxidizing.	The evidence indicates that this potentially adverse condition is present at Yucca Mountain: water is expected to contain dissolved oxygen and be chemi-cally oxidizing.

Table 6-21. Summary of analyses for Section 6.3.1.2; geochemistry (10 CFR 960.4-2-2) (continued)

Condition	Department of Energy (DOE) finding
QUALIFYING CONDITION	
The present and expected geochemical characteristics a site shall be compatible with waste containment and isolation. Considering the likely chemical interactions among radionuclides, the host rock, and the ground water, the characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.	Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): releases to accessible environment are expected to be nearly zero for 10,000 years; unsaturated emplacement zone has benign chemistry and extremely low water flux, which are expected to aid engineered barrier performance.

history of zeolitization of the tuffs has also been studied (Hoover, 1968; Bryant and Vaniman, 1984; Levy 1984b; Dibble and Tiller, 1981; Waters and Carroll, 1981; Hay, 1978). The potential host rock at Yucca Mountain, a zone of devitrified tuff in the Topopah Spring Member, is composed of approximately 98 percent quartz, feldspar, and cristobalite, with lesser amounts of zeolites and clays (Daniels et al., 1982).

The concentrations (Croff and Alexander, 1980) and equilibrium chemical behavior of the radionuclides present in the waste is still under active study. However, enough is known to predict the general behavior of most elements (Apps et al., 1983; Allard, 1982). The solubilities of waste elements in representative water from Yucca Mountain under oxidizing conditions, and in similar waters have been calculated by equilibrium thermodynamic methods (Allard, 1982; Duffy and Ogard, 1982; Wolfsberg et al., 1982; Apps et al., 1983; Means et al, 1983). Experiments to determine dissolution rates of spent fuel and borosilicate glass are under way (Oversby, 1983; Bates and Gerding, 1985a,b; Bazan and Rego, 1984; Eklund and Forsyth, 1978; Bibler et al., 1984; Wilson and Oversby, 1985; Johnson et al., 1981).

The sorption ratios, R_d, (also known as the distribution coefficient) of many radionuclides have been measured by batch sorption techniques for more than 40 tuff samples from 9 different tuff units (Ogard et al., 1983a,b; Wolfsberg et al., 1983; Bryant and Vaniman, 1984). Rundberg (1985) indicates that the sorption ratios obtained by batch sorption techniques are in good agreement with sorption ratios obtained on intact tuff for simple cations. Methods for estimating geochemical retardation by the calculation of retardation factors that are based on sorption ratios have been developed (Sherwood et al., 1975). The temperatures expected in the repository have been calculated (Johnstone et al., 1984; Travis et al., 1984; Morales, 1985). The location of the sorbing minerals in Yucca Mountain is largely determined (Bish et al., 1984; Vaniman et al., 1984; Bish and Vaniman, 1985), though stratigraphic details remain to be resolved. The stability of the sorbing minerals is less certain (Bish and Semarge, 1982; Smyth, 1982), but information on some reactions is available (Smyth, 1982). Retardation factors in Yucca Mountain tuffs have been estimated (Travis et al., 1984; Sinnock et al., 1984).

The flux of water through the unsaturated zone at Yucca Mountain has been estimated from several lines of evidence (Section 6.3.1.1.5). Water from wells in the vicinity of Yucca Mountain has been analyzed, and species naturally present in the water can be estimated (Benson et al., 1983; Daniels et al., 1983). The dissolved oxygen content of water in the unsaturated zone has been calculated (Linke, 1965) and the solubility of spent fuel in an oxidizing environment estimated (Lemire and Tremaine, 1980). Little quantitative information is available about the formation of colloids or the particulate content of water from the vicinity of Yucca Mountain (Rai and Swanson, 1981; Newton and Rundberg, 1984; Avogadro et al., 1982; Avogadro and DeMarsily, 1984; Kim et al., 1984; Olofsson et al., 1984). The potential for matrix diffusion to retard radionuclides in fractured rock with a low matrix permeability has been studied (Neretnieks, 1980). The porosity of tuffs at Yucca Mountain (Johnstone and Wolfsberg, 1980) and the effective diffusivities of tuffs from Yucca Mountain and Rainier Mesa (Walter, 1982; Daniels et al., 1983) have been measured.

Reactions of Topopah Spring tuff with Well J-13 water at 90 and 150°C (194 and 302°F) have been experimentally determined (Knauss et al., 1984; Oversby and Knauss, 1983). Data on the laboratory synthesis of some of the minerals in the tuff are available (Hawkins, 1981; Chi and Sand, 1983) and can be supplemented by the results of hydrothermal experiments (Wolfsberg et al., 1983; Allen et al., 1984) and thermodynamic calculations (Daniels et al., 1983). The corrosion of the reference waste disposal container material (austenitic stainless steel) in the expected repository environment has been studied (McCright et al., 1983; Oversby, 1985).

Assumptions and data uncertainties

Indirect methods have been used to estimate the initiation and duration of geochemical processes resulting in the alteration of minerals (Bryant and Vaniman, 1984) because techniques for the direct age dating of alteration products at the Yucca Mountain site have not been fully developed. Clinoptilolite and mordenite now present in Yucca Mountain are assumed to have been there for at least 10 million years. A temperature increase up to 85°C (185°F) total should not produce significant reaction of clinoptilolite to other minerals (Smyth, 1982).

For discussions about precipitation and complex formation of waste elements, equilibrium chemical behavior is assumed. Discussions about colloid formation are based on empirical observations. For sorption, the minerals present in the rock when it is crushed include altered minerals typically found in fracture fillings. These minerals are assumed to be more sorptive than the typical matrix minerals. Estimates of retardation factors are based on the assumption of equilibrium conditions.

Because there is uncertainty in the flux and flow mechanisms of water at Yucca Mountain, conservatively high flux values were used in some of the analyses. Although water from the saturated zone of Yucca Mountain has been characterized, the solubilities of many waste elements in that water have not yet been experimentally determined and are therefore estimated by calculations using a computer model (Wolfsberg et al., 1982). The models used to estimate waste element dissolution rates incorporate a number of assumptions about water flow, waste element diffusivities in the water, and solid waste form characteristics (Kerrisk, 1984; Oversby and Wilson, 1985). The assumptions that were made for the analysis are considered conservative.

Another area of uncertainty involves fracture parameters. Important parameters affecting flow, such as fracture aperture, fracture spacing, and connectivity, are poorly known. Under the conditions of fracture flow, chemical retardation factors based on equilibrium conditions may not be accurate; with fracture flow, the kinetics of adsorption, absorption, and diffusion could become important. If fracture flow occurred, then radionuclide transport could be more rapid than that under matrix flow conditions. If radionuclide transport is significantly increased by the formation of colloids or complexes, then there will be uncertainty about retardation coefficients and diffusivities.

Analyses of precipitation and the formation of particulates, colloids, and inorganic or organic complexes are generally based on qualitative assessments of the general behavior of aqueous chemical systems. Estimates

of geochemical retardation are based on the retardation factor calculated from sorption measurements. Geochemical retardation, however, is defined as a combination of the processes of sorption and matrix diffusion. This produces uncertainty in interpretations based on sorption measurements and retardation factors because other processes could also affect retardation.

The dissolution rates of elements from solid waste at Yucca Mountain were estimated by using models in which dissolution rates are limited by the diffusion of elements into water flowing past the waste (Kerrisk, 1984). Waste elements are assumed to be saturated at the waste-water interface. This model has been proposed as being more realistic than leach-rate models (Chambre et al., 1982). Experimental data that validate this proposal are now becoming available (Oversby, 1983; Chick and Pederson, 1984; Grambow and Strachan, 1984). Another model is based on the assumption that all of the water flowing through the repository becomes saturated with each waste element (Kerrisk, 1984). The results from this model are conservative; they represent upper limits on the dissolution rates of waste elements, not the expected values. A third model, based on radionuclide releases from spent fuel and high-level waste in cracked waste disposal containers (Oversby and McCright, 1984), has also been used to estimate upper limits on release rates (Oversby and Wilson, 1985).

6.3.1.2.3 Favorable conditions

(1) The nature and rates of the geochemical processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.

Evaluation

In the discussions that follow, geochemical processes have been divided into two categories: (1) the processes that could involve mineralogic reactions and changes in mineral assemblages within the geologic repository and (2) unspecified geochemical processes that could affect the stability of the ground-water chemistry. The approach to establishing this favorable condition with regard to geochemical processes of the first category has been to identify geochemical processes resulting in mineralogic changes and to determine the nature and rate of such changes.

The dominant pre-Quaternary geochemical processes resulting in mineralogic changes at Yucca Mountain are the alteration of volcanic glass to the zeolites clinoptilolite and mordenite and to minor clay minerals and the recrystallization of this mineral assemblage to analcime, feldspar, and quartz. Although the process of zeolitization is interpreted as a diagenetic alteration of glassy tuffs below the water table, there is evidence (Hoover, 1968; Bryant and Vaniman, 1984) of possible zeolitization near or above the water table. The alteration of glass to zeolites and clay is a favorable geochemical process because it increases the radionuclide sorptive capacity of the affected rock. Although this increased sorptive capacity is a favorable condition, the increased water content may produce other unknown

effects that are not necessarily favorable. Therefore, a zeolitization rate close to zero may be the most favorable condition.

Petrofabric studies of the altered rocks, combined with information about the tectonic history of the area, indicate that the zeolitic alteration of glasses at Yucca Mountain predated the Quaternary Period (Bryant and Vaniman, 1984). A separate episode of zeolitization, localized in the lower Topopah Spring Member of the Paintbrush Tuff was probably related to the original cooling of the unit and therefore also predated the Quaternary Period (Levy, 1984b). Because this geochemical process was probably not operating during the Quaternary Period (Bryant and Vaniman, 1984), its Quaternary rate is inferred to be close to zero. Barring climatic changes that would significantly increase ground-water recharge or raise the static water level at Yucca Mountain, zeolitization should be inoperative or minor during the next 100,000 years. However, zeolitization could occur either in the upper tuffaceous beds of Calico Hills or in stratigraphically higher rock units if the environment becomes wet enough for these rocks to become saturated.

Studies of mineral-assemblage transitions associated with increasing depth and elevated subsurface temperatures suggest that the recrystallization of clinoptilolite-mordenite assemblages to analcime assemblages may have occurred during the Quaternary Period and may continue during the next 100,000 years. This recrystallization is of interest because it could reduce the amount of sorptive zeolites present along potential flow paths and thus reduce the radionuclide sorptive capacity at Yucca Mountain (Daniels et al., 1982). This type of recrystallization has taken place at Yucca Mountain at depths greater than about 945 meters (3,100 feet); factors affecting the recrystallization include time, temperature, and pore fluid chemistry (Dibble and Tiller, 1981). The time required to reach equilibrium when an intermediate metastable zeolite mineral assemblage must recrystallize to a stable analcime assemblage was estimated at tens of millions of years by Dibble and Tiller (1981) from examinations of numerous natural zeolite occurrences. The rate and extent of present and future recrystallization at Yucca Mountain can be estimated by examining the clinoptilolite-analcime boundary. The interval within which clinoptilolite disappears and analcime becomes the dominant zeolite is about 15 to 30 meters (50 to 100 feet) thick, in which clinoptilolite (with or without mordenite) coexists with small amounts of analcime (Waters and Carroll, 1981; Caporuscio et al., 1982). This transition zone occurs at depths of 450 to 750 meters (1,475 to 2,460 feet) below the repository level. If recrystallization is occurring within this interval and proceeds to completion within 100,000 years, then the amount of sorptive zeolites lost would be an insignificant portion of the sorptive zeolites remaining in the overlying rocks. Furthermore, the current understanding of the flow processes at Yucca Mountain (see Section 6.3.1.1.5) would not suggest radionuclide movement at this depth because the recrystallization occurs at least 200 meters (656 feet) below the water table.

The second category, unspecified geochemical processes, can be evaluated in terms of the predictability of the host-rock performance in isolating waste for 100,000 years into the future. In order not to affect the isolation capability, the composition of the ground water must remain unchanged or must exhibit only minor changes in the concentration of oxygen, the bicarbonate ion, and dissolved organic carbon because these are the main

constituents that affect speciation, sorption, and the solubility of waste elements in Yucca Mountain ground water (Daniels et al., 1983). To favorably affect the ability of the host rock to isolate waste, the amount of dissolved oxygen or the amount of the bicarbonate ion in solution would have to decrease because, under the present oxidizing conditions of the ground water (Daniels et al., 1983), the multivalent waste elements have higher solubilities than they would under reducing conditions and the bicarbonate ion is the major complexing ligand (Wolfsberg et al., 1982). In the first meter of surface material, the organic content of vegetation and microbes is a major reactant with the oxygen from the atmosphere that is carried along with infiltrating water. Because the amount of organics is low and also not expected to increase drastically even if the arid environment becomes semiarid during future pluvials (Section 6.3.1.4), the oxygen concentration of the water is not expected to change with time. The low organic content of the ground water (Means et al., 1983) is also not expected to change drastically or contribute to waste element complexing (favorable condition 2). The bicarbonate concentration in the ground water probably depends on carbon dioxide in the air, the respiration of plants and organisms in the soil cover, infiltration rates, and the dissolution of carbonate-containing minerals along flow paths. At this time, it cannot be stated how large the change in the bicarbonate concentration could be during the next 100,000 years. Constraints will be established during site characterization through laboratory studies and analyses of rock samples along expected flow paths.

Conclusion

Site characterization must be conducted before sufficient information will be available to identify all of the geochemical processes that could affect ground-water chemistry. It is, however, possible to draw conclusions about the geochemical processes that involve mineralogic reactions and changes in mineral assemblages. At Yucca Mountain, such processes occurred before the Quaternary Period and should be absent or minor during the next 100,000 years. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(2) Geochemical conditions that promote the precipitation, diffusion into the rock matrix, or sorption of radionuclides; inhibit the formation of particulates, colloids, inorganic complexes, or organic complexes that increase the mobility of radionuclides; or inhibit the transport of radionuclides by particulates, colloids, or complexes.

Because of the complexity of this favorable condition, the evaluation for each component is presented individually in the sections that follow.

Evaluation for geochemical conditions that promote the precipitation of radionuclides

The pH of water from wells near Yucca Mountain generally ranges from 7 to 8 (Daniels et al., 1983). Oxides of many waste elements, particularly the actinides, have high solubilities at low and high pH, with a minimum solubility in the pH range of 6 to 8 (Allard, 1982; Duffy and Ogard, 1982). Thus, the nearly neutral pH of water from the Yucca Mountain area provides conditions that favor minimum solubilities for these elements. Minimum solubility is likely to promote geochemical conditions conducive to

precipitation of dissolved material. Other conditions, if any, that promote precipitation of dissolved material at and near the proposed repository have yet to be defined.

Evaluation for geochemical conditions that promote diffusion into the rock matrix

In fractured rock with a low matrix permeability, matrix diffusion is expected to slow the movement of radionuclides in comparison to the velocity of ground water. Neretnieks (1980) calculated the exent of this effect for granite, which has a porosity of 0.004 to 0.009. In studies with nonsorbing tracers, the travel time of the tracer (defined at some arbitrary concentration relative to the input concentration) relative to the travel time of the water is proportional to the square of the porosity, all else being equal (Daniels et al., 1982). The porosity of tuffs at Yucca Mountain ranges from 0.11 to 0.50 (Johnstone and Wolfsberg, 1980). In the evaluation described below, matrix porosity is assumed to be constant, and the pores are assumed to be connected so that the diffusivity is not a function of scale. The permeability of the rock matrix is assumed to be negligible in comparison with the fracture permeability.

Travis et al. (1984) have performed modeling studies based on these theories and assumptions. By further assuming steady-state flow conditions and fractures that have not become lined by precipitation of minerals so that fracture-matrix transfer cannot occur, Travis et al. (1984) suggest that diffusion may provide delay factors (referred to as retardation factors) in Yucca Mountain tuff units of as much as 400 for nonsorbing species and several thousand for sorbing species. The physical implication of these retardation factors is that ground water (with or without dissolved radionuclides) entering a fracture will be diffused into the matrix and back into the fracture, thereby leading to a circuitous ground-water travel path. The resultant effect of this is that the radionuclide transport time will be lengthened by a factor equivalent to the retardation factor. Under transient (nonsteady-state) conditions, Sinnock et al. (1984) have estimated that the retardation factor for Yucca Mountain tuff units, using the same assumptions of fracture/matrix moisture transfer, can be conservatively considered to be 100 for nonsorbing species. This value has been qualitatively used in sections 6.3.1.1.4 and 6.3.1.4.4. to evaluate the potential effect of changing climatic conditions on radionuclide transport.

Because the proposed repository at Yucca Mountain is located in the unsaturated zone, the possibility of vapor transport of waste elements exists. Two aspects of vapor transport are important. The first is that only certain waste elements can be transported in significant quantities in the gas phase under the conditions anticipated at and near the repository. In particular, noble gases such as xenon, krypton, or radon, carbon as carbon dioxide, tritium as H_2 gas or as water vapor, or iodine as I_2 vapor are possible waste elements that can be transported as gases or vapors. The second is that the aqueous phase in the unsaturated zone can retard the movement of some waste elements because they are soluble in liquid water. These waste elements will be partitioned between the gas and aqueous phases in the unsaturated zone. All of the fission-product isotopes of xenon and krypton are stable or relatively short-lived (less than 11-year half-life) except for krypton-81, which has a half-life of 200,000 years. These noble

gas radionuclides with short half-lives will decay away during the period of substantially complete containment of the waste (300 to 1,000 years). Tritium also has a short half-life (12 years) and thus should decay away during the containment period. The radionuclide krypton-81 is present in very small quantities (Croff and Alexander, 1980) and should not pose a significant problem. Isotopes of radon will not be present as fission products, but will be produced as part of actinide decay chains. No other members of actinide decay chains are gases, so gaseous transport could only start after radon production. All of the radon isotopes have short enough half-lives (less than 4 days) to preclude gaseous transport over long distances. Two radionuclides that may be transported in the gas phase and that will be present for long periods of time are carbon-14 and iodine-129. The likely gaseous forms of both these radionuclides (CO_2 and I_2) are soluble in water and thus their transport as gases may be retarded. These topics, however, will be addressed further during site characterization.

Evaluation for geochemical conditions that promote the sorption of radionuclides

The probable flow paths from a repository in the unsaturated Topopah Spring Member to the accessible environment traverse stratigraphic zones that contain an abundance of highly sorptive minerals, particularly zeolites and clays. Water will flow from the repository downward to the water table and then laterally along paths defined by the hydraulic gradient and the hydraulic conductivity of the rock. These paths will be in part through the tuffaceous beds of Calico Hills, which contain significant quantities of zeolites and clays (i.e., clays greater than 5 percent, zeolites greater than 10 percent).

Other formations that might also be in the path of flow, the Prow Pass, the Bullfrog, and the Tram members of the Crater Flat Tuff, have zones containing zeolites and clays in variable abundances (smectite, heulandite, clinoptilolite, and (or) mordenite). Distributions of abundant (i.e., greater than 10 percent) sorptive zeolites in the rock matrix are summarized on the map and cross sections in figures 6-10 to 6-13. Four principal intervals of zeolitization have been identified at Yucca Mountain (Bish et al., 1984). These intervals are described on the following pages and in Table 6-22 for each of the drill holes on the cross sections.

1. Interval I: The zeolite- and clay-rich zone at the top of the lower Topopah Spring vitrophyre. Although thin (generally less than 3 meters (10 feet), this interval is important because it is at the immediate base of the host rock and is everywhere above the static water level (SWL). This zeolitized interval is unique because it is within the densely welded region of a compound cooling unit, whereas zeolitization is generally restricted to the poorly welded or nonwelded margins of cooling units.

2. Interval II: The relatively thick zeolitized zone that occurs in places in the bedded, nonwelded, and poorly welded tuffs that form the base of the Topopah Spring Member and the underlying tuff of Calico Hills, and often extends into the top of the Prow Pass Member of the Crater Flat Tuff. The base of the Topopah Spring Member is the lower margin of a compound cooling unit, providing a predictable
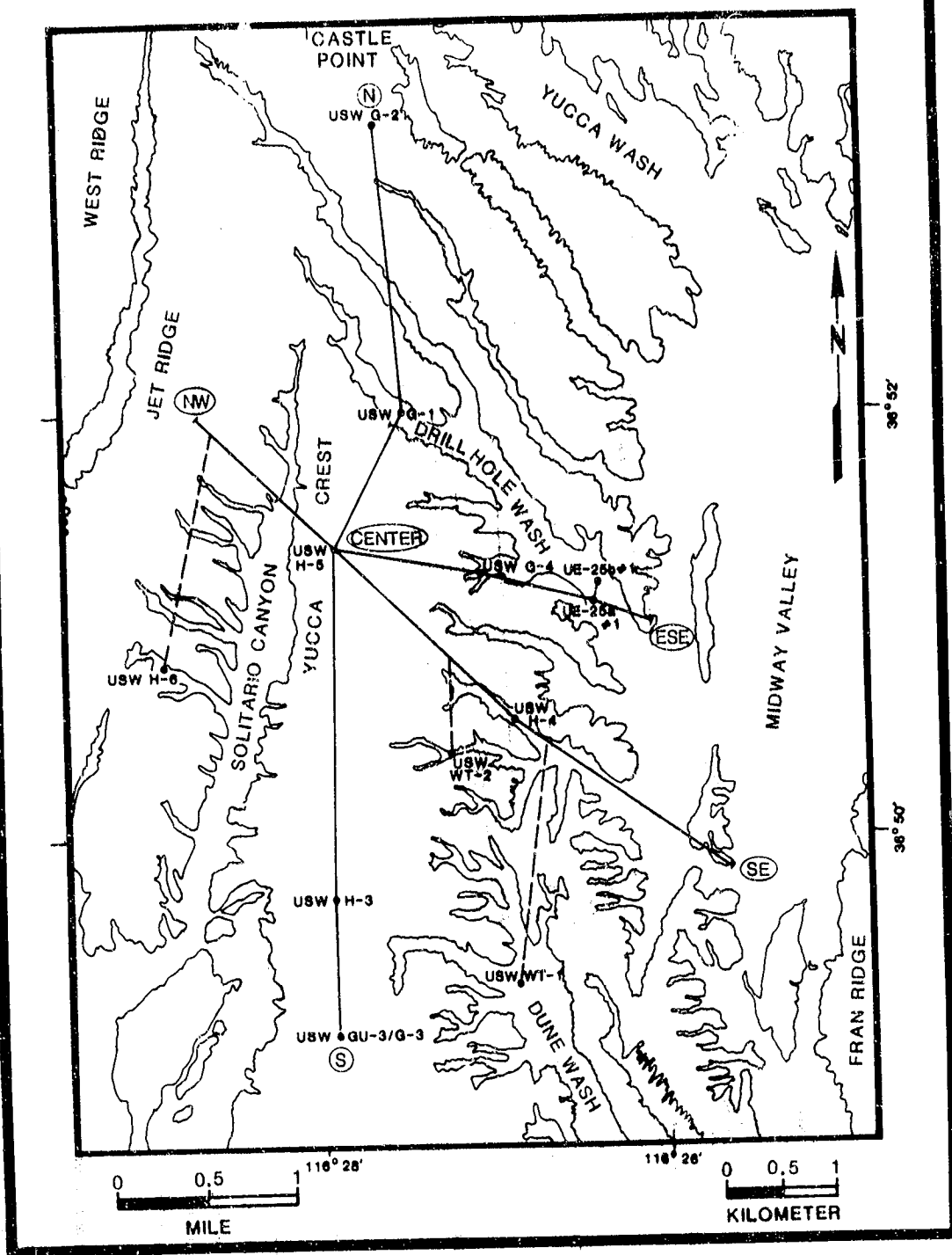
Figure 6-10. Plan view of the Yucca Mountain area based on the map by Scott and Bonk (1984). Locations of drill holes are indicated along with the orientations of cross sections used in figures 6-11 through 6-13 with zeolite zonation represented on the geologic cross sections drawn from Scott and Bonk (1984). Several drill holes (USW H-6, WT-1, WT-2, and UE-25b#1) are projected onto the cross sections. Modified from Bish and Vaniman (1985).
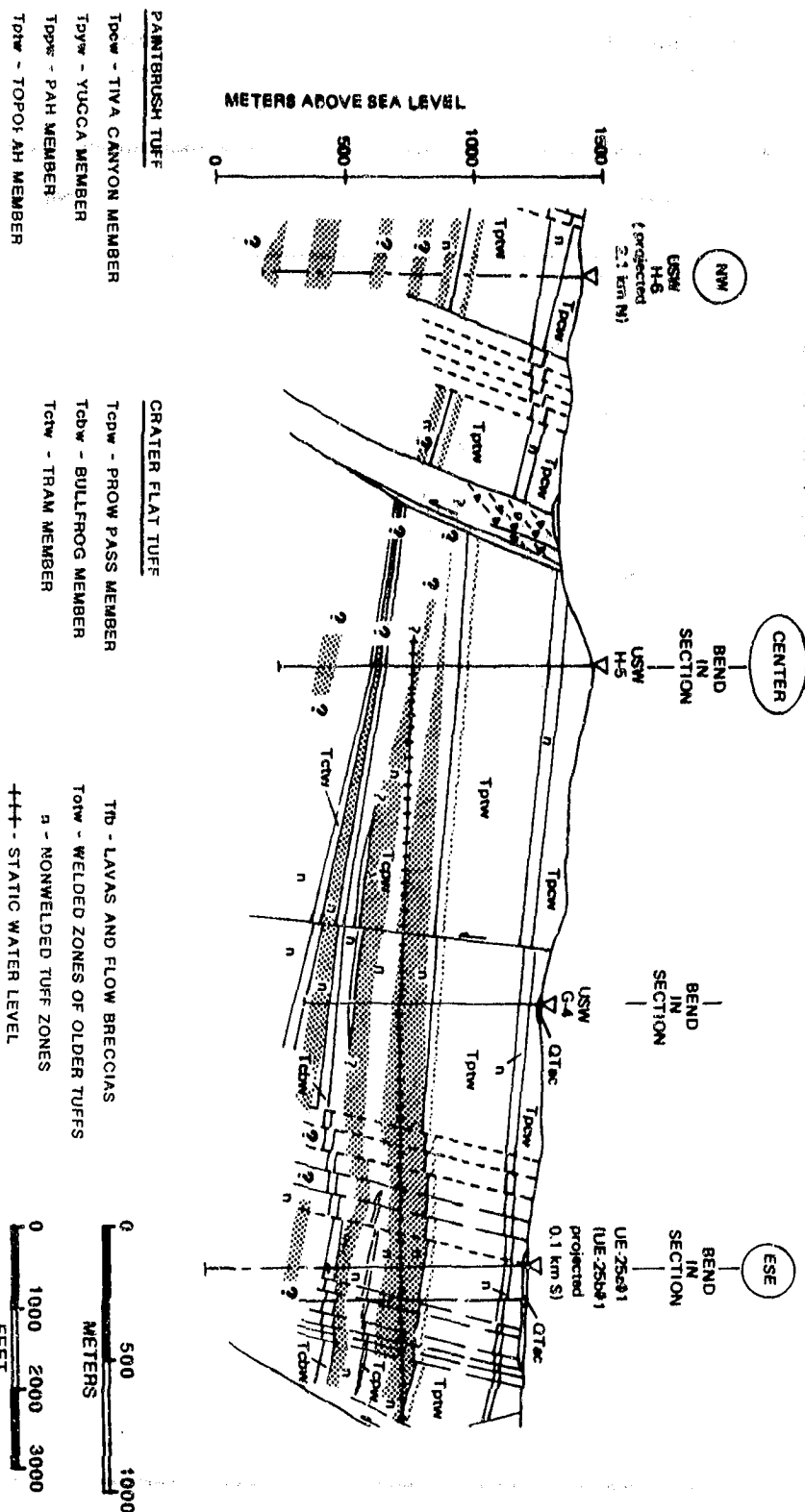
Figure 6-11. Major intervals containing the sorptive minerals clinoptilolite or mordenite. The intervals within the lower Tptw (above the basal vitrophyre) consist mostly of heulandite (isostructural with clinoptilolite). Mordenite may be completely absent in some parts of these mapped intervals (e.g., in USW G-3 and GU-3). Modified from Bish and Vaniman (1985).

PAINTBRUSH TUFF

Tpcw – TIVA CANYON MEMBER

Tpyw – YUCCA MEMBER

Tppw – PAH MEMBER

Tptw – TOPOPAH MEMBER

CRATER FLAT TUFF

Tcpw – PROW PASS MEMBER

Tcbw – BULLFROG MEMBER

Tctw – TRAM MEMBER

Tfb – LAVAS AND FLOW BRECCIAS

Totw – WELDED ZONES OF OLDER TUFFS

n – NONWELDED TUFF ZONES

++++ – STATIC WATER LEVEL

METERS ABOVE SEA LEVEL
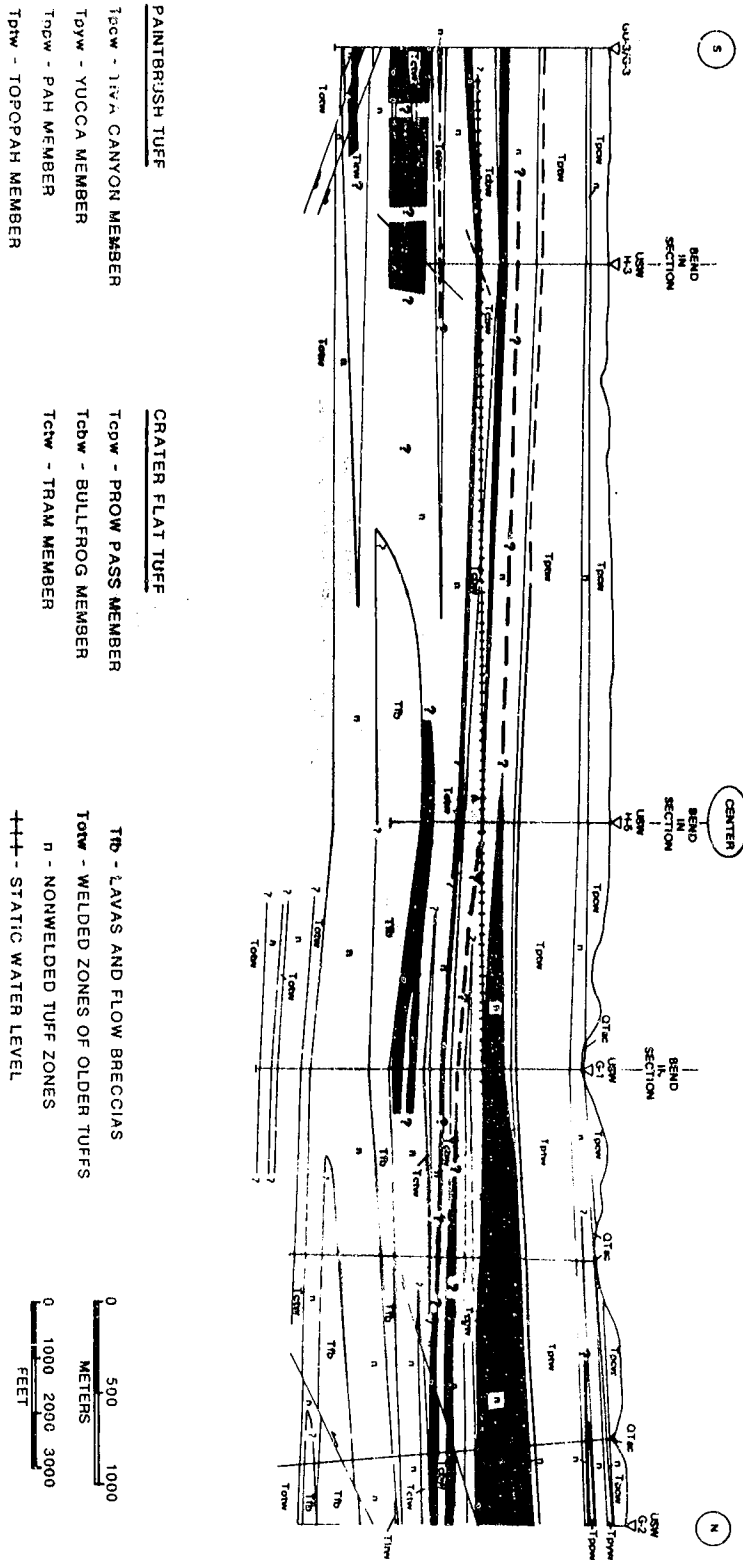
Figure 6-12. Major zeolite distributions, north-south cross section. Modified from Bish and Vaniman (1985).

METERS ABOVE SEA LEVEL

PAINTBRUSH TUFF

Tpcw - TIVA CANYON MEMBER

Tpyw - YUCCA MEMBER

Tppw - PAH MEMBER

Tptw - TOPOPAH MEMBER

CRATER FLAT TUFF

Tcpw - PROW PASS MEMBER

Tcbw - BULLFROG MEMBER

Tctw - TRAM MEMBER

Tfb - LAVAS AND FLOW BRECCIAS

Totw - WELDED ZONES OF OLDER TUFFS

n - NONWELDED TUFF ZONES

+++ - STATIC WATER LEVEL
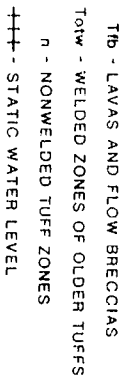
Figure 6-13. Major zeolite distributions, from center of Figure 6-10 to the southeast. Modified from Bish and Vaniman (1985).

Table 6-22. Commonly zeolitized intervals at Yucca Mountain[a,b]

Zeolitized intervals	USW G-1 SWL=577 m deep	UE-25a#1 UE-25b#1 SWL=471 m deep	USW G-4 SWL=541 m deep	USW H-4 SWL=519 m deep	USW H-5 SWL=704 m deep	USW H-3 SWL=754 m deep	USW GU-3 USW G-3 SWL=754 m deep
Interval I: base to the lower Topopah Spring vitrophyre	Depth: 392-393 m (1 m thick) 15% cpt	Depth: 385-398 m (3 m thick) 7% cpt	Depth: 396-401 m (5 m thick) 10% (+12) cpt	Depth: 357-361 m (4 m thick) No samples	Depth: 485 m 10% cpt No samples	Depth: 367-371 m (4 m thick) Trace cpt	Depth: 360-364 m (4 m thick)
Interval II: base of the Topopah Spring unit, tuff of Calico Hills	Depth: 425-565 m (140 m thick) 52% (+17) cpt	Depth: 404-556 m (152 m thick) 67% (+6) cpt 17% (+20) mord	Depth: 420-545 m (125 m thick) 50% (+19) cpt 5% (+7)	Depth: 400-504 m (104 m thick) 63% (+13) cpt 8% (+12) mord	Depth: 584-594 m (10 m thick) 37% cpt	Vitric (nonzeolitized)	Vitric (nonzeolitized)
Interval III: between the Prow Pass and Bullfrog units	Depth: 622-706 m (84 m thick) 45% (+12) cpt 18% (+18) mord	Depth: 636-710 m (74 m thick) 60% cpt & mord	Depth: 600-682 m (82 m thick) 32% (+12) cpt 19% (+10) mord	Depth: 596-698 m (102 m thick) No samples	Depth: 665-689 m (34 m thick) 60% cpt	Depth: 549-610 m (61 m thick) 68% cpt	Depth: 557-613 m (56 m thick) 58% (+18) cpt
Interval IV: between the Bullfrog and Tram units	Depth: 779-823 m (44 m thick) 37% (+6) cpt 15% (+11) mord	Depth: 863-890 m (27 m thick) 4% (+4) cpt 16% (+10) mord	Depth: 828-860 m (32 m thick) 9% (+9) cpt 35% (+33) mord	Depth: 765-774 m (9 m thick) No samples	No samples	Depth: 732-760 m (28 m thick) 52% (+17) cpt 18% (+13) mord	Depth: 776-822 m (46 m thick) 36% (+8) cpt

[a] Data from VanLuman et al. (1984).
[b] 1 meter (m) = 3.281 feet;
cpt = clinoptilolite and heulandite;
mord = mordenite;
SWL = static water level.

locale for zeolitization. The tuff of Calico Hills is only partly welded to nonwelded throughout and is thoroughly zeolitized across the northern and eastern part of the primary repository area. However, along the rest of Yucca Mountain this interval may be incompletely zeolitized (USW H-5) or nonzeolitized and vitric (USW GU-3) (Vaniman et al., 1984).

3. Interval III: The partly welded and bedded tuffs at the base of the Prow Pass Member and at the top of the underlying Bullfrog Member compound cooling unit. This interval is consistently zeolitized throughout Yucca Mountain in the vicinity of the primary repository area (Vaniman et al., 1984), although it merges with Interval II in Jackass Flats (data from Well J-13, to the east of the cross sections shown).

4. Interval IV: The poorly welded and bedded tuffs at the base of the Bullfrog Member compound cooling unit and at the top of an underlying cooling unit within the uppermost Tram Member. This interval persists throughout the primary repository area (Vaniman et al., 1984).

Batch sorption techniques have been used to estimate sorption ratios for many radioactive elements, including cesium, strontium, barium, radium, uranium, neptunium, plutonium, americium, technetium, europium, cerium, and, to a limited degree, selenium and tin. The sorption ratio (also known as the distribution coefficient), R_d, is defined as

$$R_d = \frac{\text{activity of radionuclide on solid phase per unit mass of solid}}{\text{activity of radionuclide in solution per unit volume of solution}} \quad (6-1)$$

Rundberg (1985) indicates that sorption ratios obtained in crushed tuff experiments, such as batch sorption techniques, are in good agreement with sorption ratios obtained on intact tuff for simple cations. More than 40 tuff samples from 9 different tuff units were obtained from cores taken at varying depths from a number of drill holes at Yucca Mountain. Tables 6-23a, 6-23b, 6-24a, and 6-24b give average sorption and desorption results for these tuff samples using ground water obtained from Well J-13. Details can be found in Daniels et al. (1982), Ogard et al. (1983a,b), Wolfsberg et al. (1983), and Bryant and Vaniman (1984).

The sorption data for many of the elements studied can be correlated with mineral composition (Daniels et al., 1982). For the alkali metals (e.g., cesium) and alkaline earths (e.g., strontium, barium, and radium), which probably exist in ground water as uncomplexed ions and sorb by ion exchange, sorption is correlated with the presence of clinoptilolite and the smectite clays, which contain exchangeable cations. Since there are large quantities of clinoptilolite directly below the proposed repository horizon, cesium, strontium, and radium should be strongly sorbed, and their movement along the flow path should be retarded.

A correlation with mineral composition is also found for the sorption of cerium, europium, plutonium, and americium, but the relation is not as clear as that for the alkali metals. However, the sorption ratios are high (100 to more than 1,000 milliliters per gram). The sorption ratios of these elements

Strat.[c] unit	Sample	depth (feet)	Sr	Cs	Ba	Ra	Ce	Eu
Tpc	JA-8	60?	270(5)[d]	2,700(400)[d]	435(15)[d]			2,100(300)[d]
	YM-5	25?	280(80)	5,800(800)	1,100(200)		450,000[d] (240,000)	2,300,00 (40,000)
Tpp	G2-547	547	265(10)[f]	13,300 (1,500)	3,490(30)[f]			340(30)[f]
	G2-723	723	290(40)[f]	4,100 (600)[f]	3,500 (400)[f]			>10,000[f]
	GU3-433	433	45(9)[g]	630(20)[g]	810(100)[g]			100(14)[g]
	GU3-855	855						
Tpt	YM-22	848	53(4)	290(30)	900(30)		1,270(40)	1,390(110)
	GU3-1203	1,203	42(1)[f]	350(30)[f]	640(40)			190(2)
	G1-1292	1,292	200(6)[f]	430(28)[f]	2,100(300)[f]	1,500(100)	66(8)[d]	140(14)[d]
	GU3-1301	1,301	28(4)[g]	160(40)[g]	570(60)[g]			45(12)[g]
	YM-30	1,264	260(80)	855(5)	3,400(1,500)		230,000 (100,000)	160,000 (50,000)
	JA-18	1,420	17,000 (3,000)	16,000 (1,000)	38,000 (18,000)		2,800 (1,400)[g]	1,400(200)[g]
Th	G1-1436	1,436	36,000 (3,000)	7,800 (500)	150,000 (24,000)		59,000 (7,000)	30,000 (2,000)[f]
	G2-1952	1,952	2,200(400)[f]	63,300 (1,100)[f]	25,000 (4,000)[f]			89(14)[f]
	GU3-1436	1,436						
bt	GU3-1531	1,531						
	YM-38	1,504	17,000 (2,000)	13,000 (2,000)	100,000 (10,000)		760(140)	1,600(200)
	YM-42	1,824	3,900(600)	17,000 (1,000)	94,000 (14,000)		49,000 (7,000)	52,000 (4,000)
Tcp	G1-1854	1,854	60,000 (14,000)	13,000 (2,000)	45,000 (7,000)			15,000
	YM-45	1,930	195(14)	520(90)	1,200(100)		730(100)	1,600(200)
	G1-1883	1,883	22(0.2)	187(3)	183(12)		1,420(20)	
	YM-46	2,002	190(60)	840(6)	14,000 (6,000)		310,000 (110,000)[f]	307,000 (110,000)
	G1-1982	1,982	55(4)	1,120(110)	700(50)		560(40)[f]	970(150)
	YM-48	2,114	2,100(400)	9,000(4,000)	18,000 (6,000)		1,400(500)	2,200(500)
	YM-49	2,221	3,200(300)	36,000 (3,000)	42,000 (8,000)		550(100)	1,200(100)
	JA-26	1,995	95(35)	1,500(600)	800(300)			
Tcb	JA-28	2,001	94(20)	1,640(210)	820(50)			2,100(1,000)
	G1-2233	2,233	48,000 (3,000)[f]	13,500 (800)	250,000 (30,000)		1,400(300)	900(200)
	G1-2289	2,289	7,300(500)	37,000 (13,000)	66,000 (9,000)	46,000 (20,000)		797(10)
	YM-54	2,491	62(12)	180(40)	400(150)		150(40)	470(40)
	G1-2333	2,333	180(20)	1,400(130)	1,500(200)			2,300(400)
	G1-2363	2,363	64(3)	470(40)	235(9)	540(60)		730(50)
	G1-2410	2,410	169(1)	1,250(50)	1,780			440(80)
	JA-32	2,533	57(3)	123(4)	380(30)		82(14)	90(30)
	G1-2476	2,476	41(1)	700(40)	385(11)			3,200(100)
Tct	G1-2698	2,698	42,000 (3,000)[f]	7,700(400)[f]	63,000 (5,000)[f]		240(30)[f]	200(30)[f]
	G1-2840	2,840	860(1)	2,200(200)	2,070(70)			4,900(400)
	G1-2854	2,854	94(1)[f]	1,080(120)[f]	1,000(50)			1,300(200)
	G1-2901	2,901	68(1)[f]	1,290(110)[f]	1,600(200)[f]		42,000 (3,000)[f]	160,000 (50,000)[f]
	G1-3116	3,116	2,400(17)[f]	6,600(500)[f]	12,000 (4,000)[f]		100(10)[f]	760(60)[f]
	JA-37	3,497	287(14)	610(40)	760(150)			6,000(800)
Tl	G1-3658	3,658	13,000(0)	4,950(50)	13,500 (500)		1,000(200)[f]	530(40)
Tba	G2-3933	3,933	240(60)[f]	2,500(1000)[f]	1,700(500)[f]			1,500(700)[f]

Table 6-23b. Average sorption ratios (distribution coefficients) from batch sorption experiments on crushed tuff for Am, Pu, U, Se, Tc, Np[a,b]

Strat. unit[c]	Sample	depth (feet)	Sorption ratios (milliliters per gram)					
			Am	Pu	U	Se	Tc	Np
Tpc	JA-8	306						
	YM-5	251						
Tpp	G2-547	547	13,000(110)[f]	1,200(120)	9.4(0.1)	2( )	0[f]	
	G2-723	723	890,000 (49,000)	>4,500	2.4(0.6)	19( )	0[f]	
	GU3-433	433	3,400(200)[d]	330(60)[g]	0	15(5)	0	7.9(0.1)
	GU3-855	855			10(0.7)	10(0.4)		
	GU3-916	916		250(25)			0.72(0.2)	4.9(1)
Tpt	YM-22	848	1,200(130)[d,e]	64(20)[d]	1.8(0.2)[d]		0.3(0.14)[d]	7.0(1.0)
	GU3-1203	1,203	1,100(120)[g]	360(40)[g]	0	(1)	0	2.7(0.1)
	G1-1292	1,292						
	GU3-1301	1,301	1,800(160)[g]	290(40)[g]	0	7(2)	0.03(0.001)	5.0(0.1)
	YM-30	1,264						
	JA-18	1,420	180(30)	120(20)	2.5(0.4)			
Th	G1-1436	1,436						
	G2-1952	1,952	1,700(70)[f]	66(6)[f]	0	2(1)		2.7(0.1)
	GU3-1436	1,436			20(2)	3(10)		
bt	GU3-1531	1,531			54(9)	5(1)		
	YM-38	1,504	14,600(1,000)	140(30)	5.3(0.2)			11.0
	YM-42	1,824						
Tcp	G1-1854	1,854						
	YM-45	1,930						
	G1-1883	1,883	470(300)					
	YM-46	2,002		77(11)				6.4
	G1-1982	1,982						
	YM-48	2,114						
	YM-49	2,221	4,300(1,400)				0.15(0.02)	
	JA-26	1,995		230(50)[e]			0.21(0.02)	9(3)
Tcb	JA-28	2,001						
	G1-2233	2,233						
	G1-2289	2,289						
	YM-54	2,491	153(6)	80(20)	1.3(0.3)	9(1)	4.2(0.5)[h]	
	G1-2333	2,333						
	G1-2363	2,363		110		25(5)		
	G1-2410	2,410			2.2(0.9)			
	JA-32	2,533	130(30)					
	G1-2476	2,476						
Tct	G1-2698	2,698						
	G1-2840	2,840						
	G1-2854	2,854						
	G1-2901	2,901		400(70)[e]	4.6(0.3)			
	G1-3116	3,116						
	JA-37	3,497	28,000 (10,000)[e]					22
Tl	G1-3658	3,658						
Tba	G2-3933	3,923	6,600(400)		1,600(30)	0	0(1)	0.1(0.006)

[a]Data from Daniels et al. (1982); Ogard et al. (1983a); Wolfsberg et al. (1983). If no footnote is indicated, the sorption ratio in parentheses represents the standard deviation of the mean.

[b]Ambient conditions, air, 20 ± 4°C; fractions do not contain particles smaller than 75 micrometers in diameter except in fractions designated by footnote f.

[c]Stratigraphic units are as follows: Tpc = Tiva Canyon Member; Tpp = Pah Canyon Member; Tpt = Topopah Spring Member; Th = tuffaceous beds of Calico Hills; bt = Bedded tuff; Tcp = Prow Pass Member; Tcb = Bullfrog Member; Tct = Tram Member; Tl = older tuffs; Tba = bedded tuff.

[d]Nonweighted average; value in parentheses is the standard deviation of the mean.

[e]Some data were rejected in averaging.

[f]Average of data for the fraction with particles smaller than 500 micrometers in diameter (contains some particles smaller than 75 micrometers).

[g]Nonweighted average of samples taken in two different positions.

[h]Performed under controlled atmospheric conditions of nitrogen with less than or equal to 0.2 ppm O_2 and less than or equal to 20 ppm CO_2.

Table 6-24a. Average sorption ratios (distribution coefficients) from batch desorption experiments on crushed tuff for Sr, Cs, Ba, Ce, Eu[a,] (See footnotes at end of Table 6-24b)

Strat.[c] unit	Sample	depth (feet)	Sorption ratios (milliliter) per gram				
			Sr	Cs	Ba	Ce	Eu
Tpc	JA-8	606	311(3)	4,600(400)	480(50)		10,000(3,000)
	YM-5	251	320(30)[d]	8,900(600)[d]	1,200(120)[d]	3,000(30,000)[d]	36,000(14,000)[d]
Tpp	G2-547	547	210(10)[f]	8,700(550)[f]	2,900(200)[f]		1,700(600)[f]
	GS-723	723	330(4)[f]	4,300(4)[f]	4,200(10)[f]		>10,000[f]
	GU3-433	433	40(10)[g]	520(20)[g]	460(20)[g]		140(10)[g]
Tpt	YM-27	848	59(2)	365(7)	830(100)	6,500(800)	3,500(200)
	GU3-1203	1,203	47(1)[f]	340(10)[f]	720(30)		650(50)[f]
	G1-1292	1,292	120(5)[f]	510(20)[f]	1,500(100)[e,f]	600(200)[f]	600(70)[f]
	GU3-1301	1,301	80(20)[g]	185(20)[g]	675(60)[g]		100(20)[g]
	YM-30	1,264	210(30)	1,500(100)	3,100(600)	170,000(15,000)	11,000(700)
	JA-18	1,420	15,000(2,000)	17,500(700)	280,000 (50,000)	1,600(500)[e]	2,400(300)[e]
Th	G1-1436	1,436	87,000 (12,000)	24,000(2,000)	340,000 (90,000)	6,700(600)	5,300(600)
	G2-1952	1,952	4,200(200)[f]	46,000(1,400)[f]	40,000 (1,000)[f]		1,600(200)[f]
	YM-38	1,540	22,000	13,000	260,000	2,600	7,300
	YM-42	1,842	4,100(1,000)	21,000(2,000)	90,000	44,000(5,000)	64,000(3,000)
Tcp	G1-1854	1,854	72,000 (13,000)[e]	14,000(2,000)	150,000 (40,000)		4,800(700)
	YM-45	1,930	210(20)	620(110)	1,310(60)[f]	5,800(600)	7,300(900)
	G1-1883	1,883	59(1)[f]	430(4)	440(10)[f]	2,200(100)[f]	1,350(50)[f]
	YM-46	2,002	260(20)	1,800(300)	210,000 (3,000)[f]	300,000 (50,000)	31,000(2,000)
	G1-1982	1,982	322(8)[f]	2,300(200)[f]	2,780(120)[f]	7,000(800)[f]	6,370(130)[f]
	YM-48	2,114	2,700(200)	27,000(4,000)	34,000(7,000)	128,000 (300)	8,100(1,200)
	YM-49	2,221	4,400(100)	39,000(1,000)	65,000(7,000)	1,040(40)	2,100(500)
	JA-26	1,995	39(3)	1,580(90)	450(13)		2,900(200)
Tcb	JA-28	2,001	114(3)	2,400(100)	1,160(20)		12,300(500)
	G1-2233	2,233	90,000 (40,000)[f]	23,000(6,000)[f]	240,000 (80,000)[f]	20,000 (13,000)[e]	5,000(2,000)[f]
	G1-2289	2,289					
	YM-54	2,491	97(9)	310(20)	660(20)	1,000(200)	1,840(110)
	G1-2333	2,333	140(13)	1,230(100)	1,460(130)[f]		9,900(1,200)
	G1-2363	2,363	150(6)[f]	1,200(30)[f]	820(20)[f]	130,000 (6,000)[f]	6,100(300)[f]
	G1-2410	2,410	140(14)	1,120(100)	1,760(150)		6,000(3,000)
	JA-32	2,533	53(3)	175(11)	490(40)	530(120)	850(130)
	G1-2476	2,476	200(4)	1,520(0)			
Tct	G1-2698	2,698	210,000 (50,000)[f]	17,000(1,100)[f]	190,000 (80,000)[f]	2,000(400)[f]	
	G1-2840	2,840	1,540(4)	2,300(130)	2,500(200)		9,000(1,100)
	G1-2854	2,854	96(1)	1,160(20)	1,330(0)		5,000(200)
	G1-2901	2,901	67(1)[e,f]	1,380(30)[f]	1,980(30)[f]	39,000(1,000)[f]	210,000 (50,000)
	G1-3116	3,116	24,000(13,000)[f]	11,000 (3,000)[f]	160,000 (80,000)[f]	3,000(1,000)[f]	8,000(3,000)[f]
	JA-37	3,497	312(9)	850(50)	920(40)		11,000(2,000)
Tl	G1-3658	3,658	12,000(3,000)[f]	12,000(2,000)[f]	10,000(4,000)[f]	9,000(4,000)[f]	9,000(3,000)[f]
Tba	G2-3933	3,933	140(20)[f]	1,400(350)[f]	1,100(200)[f]		3,000(1,100)[f]

Table 6-24b. Average sorption ratios (distribution coefficients) from batch desorption experiments on crushed tuff for Am, Pu, U, Tc, Np[a,b]

Strat.[c] unit	Sample	Depth (feet)	Am	Pu	U	Tc	Np
				Sorption ratios (milliliters per gram)			
Tpc	JA-8	606					
	YM-5	521					
Tpp	G2-547	5?7	17,000(1,400)	1,200(170)[f]			
	G2-723	723	2.8 x 10^6 (2.6 x 10^4)	>47,000			
	GU3-433	433	9,300(1,780)[g]	920(40)[g]			
Tpt	YM-22	848	2,500(400)[d]	1,330(140)[d]	5(2)[d]	1.2(0.3)[d]	33(5)[d]
	GU3-1203	1,203	1,300(200)[g]	920(15)[g]			
	G1-1292	1,292				0	
	GU3-1301	1,301	2,500(600)[g]	1,300(460)[g]			
	YM-30	1,264					
	JA-18	1,420	1,100(300)	350(140)	9.4(1.4)		
Th	G1-1436	1,436					
	G2-1952	1,952	5,800(1,100)[g]	350(45)[g]			
	YM-38	1,540	7,100(1,200)	1,600(300)	14.8(1.0)		24(2)
	YM-42	1,824					
Tcp	G1-1854	1,854					
	YM-45	1,930					
	G1-1883	1,883	7,200(900)	890(60)			36(10)
	YM-46	2,002					
	G1-1982	1,982					
	YM-48	2,114				1.6(0.2)	
	YM-49	2,221	3,400(400)[e]	720(90)		2.0(0.3)	12(4)
	JA-26	1,995					
Tob	JA-28	2,001					
	G1-2233	2,233					
	G1-2289	2,289					
	YM-54	2,491	550(80)	720(40)	12(8)	38(-)[h]	
	G1-2333	2,333					
	G1-2363	2,363					
	G1-2410	2,410			8(2)		
	JA-32	2,533	2,200(600)				
	G1-2476	2,476					
Tct	G1-2698	2,698					
	G1-2840	2,840					
	G1-2854	2,854					
	G1-2901	2,901					
	G1-3116	3,116					
	JA-37	3,497	32,000(10,000)	1,400(300)	9.9(0.4)		170(50)
Tl	G1-3658	3,658					
Tba	G2-3933	3,933	1,200(410)	530(130)			

[a] Data from Daniels et al. (1982); Ogard et al. (1983a); Wolfsberg et al. (1983). If no footnote is indicated, the sorption ratio in parentheses represents the standard deviation of the mean.
[b] Ambient conditions, air, 20 ± 4°C; fractions do not contain particles smaller than 75 micrometers in diameter except in fractions designated by footnote f.
[c] Stratigraphic units are as follows: Tpc = Tiva Canyon Member; Tpp = Pah Canyon Member; Tpt = Topopah Spring Member; Th = tuffaceous beds of Calico Hills; Tcp = Prow Pass Member; Tcb = Bullfrog Member; Tct = Tram Member; Tl = older tuffs; Tba = bedded tuff.
[d] Nonweighted average; value in parentheses is the standard deviation of the mean.
[e] Some data were rejected in averaging.
[f] Average of data for the fraction with particles smaller than 500 micrometers in diameter (contains some particles smaller than 75 micrometers).
[g] Nonweighted average of samples taken in two different positions.
[h] Performed under controlled atmospheric conditions of nitrogen with less than or equal to 0.2 ppm O_2 and less than or equal to 20 ppm CO_2.

are undoubtedly influenced by the formation of hydroxyl and carbonate complexes. Geochemical sorption will not offer much retardation for anionic species like pertechnetate.

Estimates can be made for the geochemical retardation by sorption (Sherwood et al., 1975). The retardation factor, R_f, is related to the sorption ratio, R_d, by the expression:

$$R_f = 1 + R_d \text{ (density)} \frac{(1 - \text{porosity})}{\text{porosity}}$$ (6-2)

where the density equals the rock column density, 2.5 grams per cubic centimeter. Table 6-25 lists representative values of measured sorption data for eight radionuclide elements on samples of tuff from units most likely to be in the ground-water flow path to the accessible environment. The retardation factors, which represent the ratio of the velocity of the water to the velocity of the radionuclide under equilibrium conditions, are calculated by using Equation 6-2 and assuming porous flow, which is reasonable for the nonwelded tuff units. Except for technetium, the retardation factors significantly exceed a value of 10, indicating that the average effective radionuclide travel time to the accessible environment will be much more than a factor of 10 times longer than the average ground-water flow time to the accessible environment.

Evaluation for geochemical conditions that inhibit the formation of particulates, colloids, inorganic complexes, or organic complexes that increase the mobility of radionuclides

Species naturally present in the water at Yucca Mountain can form both solid and aqueous complexes with waste elements and thus have both favorable and unfavorable aspects (Apps et al., 1983; Daniels et al., 1983). The total organic content of water from wells near Yucca Mountain is less than 0.6 milligram per liter, and the organic species tend to have high molecular weights (higher than 300) (Means et al., 1983). This leads to organic concentrations of 1×10^{-6} moles per liter or less. The low organic content of water from Yucca Mountain will inhibit the formation of significant quantities of organic complexes with waste elements. The particulate content of water at Yucca Mountain has not yet been characterized; thus, it is not known whether particulates containing waste elements will form. Certain actinides (e.g., plutonium) are known to form colloidal particles in dilute, nearly neutral aqueous solutions (Rai and Swanson, 1981; Newton and Rundberg, 1984; Kim et al., 1984; Olofsson et al., 1984). There is not enough information available at this time to know whether geochemical conditions at Yucca Mountain will inhibit the formation of these colloids.

Evaluation for geochemical conditions that inhibit the transport of radionuclides by particulates, colloids, and complexes

Actinides leached from glass are expected to occur in the form of colloids, as has been shown for americium by Avogadro et al. (1982) and Avogadro and DeMarsily (1984). The size distribution of americium colloids in low ionic strength ground water was measured by ultrafiltration. The results of

Table 6-25. Representative sorption ratios (distribution coefficients) and retardation factors for eight radionuclide elements with Yucca Mountain tuff[a]

Waste element	Welded tuff Topopah Spring Member porosity = 11%		Bedded tuff Topopah Spring Member porosity = 35%		Bedded tuff - tuffaceous beds of Calico Hills porosity = 35%		Partially welded tuff Prow Pass Member porosity = 29%		Welded tuff Bullfrog Member porosity = 23%		Nonwelded tuff Tram Member porosity = 32%	
	Sorption ratio, R_d (ml/g)	Retardation factor[b,c]	Sorption ratio, R_d (ml/g)	Retardation factor[b,c]	Sorption ratio, R_d (ml/g)	Retardation factor[b,c]	Sorption ratio, R_d (ml/g)	Retardation factor[b,c]	Sorption ratio, R_d (ml/g)	Retardation factor[b,c]	Sorption ratio, R_d (ml/g)	Retardation factor[b,c]
Americium (Am)	250	25,000	180	820	6,600	21,000	470	2,900	140	1,200	28,000	150,000
Cesium (Cs)	290	6,000	16,000	73,000	7,800	35,000	190	1,200	180	1,500	610	3,300
Neptunium (Np)	7	150	ND[d]	ND	11	50	6.5	40	ND	ND	28	150
Plutonium (Pu)	64	1,300	120	540	140	630	77	480	80	670	400	2,200
Strontium (Sr)	53	1,100	17,000	77,000	3,900	17,000	22	140	62	520	290	1,600
Technetium (Tc)	0.3	7	2.5[e]	12	ND	ND	0.2	2	4.2[e]	36	ND	ND
Uranium (U)	1.8	37	2.5	12	5.3	26	ND	ND	1.3	12	4.6	25
Barium (Ba)	900	18,000	38,000	180,000	94,000	460,000	182	1,100	400	3,400	760	4,000

[a] Data from Daniels et al. (1982).

[b] Retardation factor $= 1 + R_d \text{(density}^c) \dfrac{(1 - \text{porosity})}{\text{porosity}}$

[c] Rock column density = 2.5 g/cm^3.

[d] ND = no data available.

[e] Controlled atmosphere—nitrogen with less than or equal to 0.2 ppm oxygen and less than or equal to 20.0 ppm carbon dioxide.

[f] Under oxidizing conditions, these values are expected to be less than 1.0.

ml/g = milliliter per gram.

these experiments showed that 70 percent of the colloid particles are larger than 0.1 micrometer and 95 percent are larger than 0.015 micrometer. In the absence of more extensive size distribution data for actinide colloids from glass leached in water that has been in contact with tuff, this size distribution provides a reasonable baseline.

Although pore-size distributions for the tuffaceous beds underlying the repository horizon are not available, mercury-intrusion porosimetry measurements have been performed on tuff samples from the zeolitized Tunnel Bed Tuff on Rainier Mesa; the results show a median pore size of 0.02 to 0.1 micrometer. If a log-normal pore size distribution is assumed, as much as 30 percent of the tuff pores are smaller than 0.01 micrometer.

In the unsaturated tuffaceous beds of Calico Hills, water is expected to move primarily through the smaller pores. The saturation is about 50 percent, and therefore water will move through pores that are smaller than the median pore size of the rock. Considering only mechanical filtration, and assuming the above size distributions for colloid particles and tuff pore size distribution, the potential exists for the bedded tuff underlying the host rock at Yucca Mountain to filter out some of the colloidal americium. This analysis ignores the potential interaction of these colloids with the tuff mineral surfaces, which could further inhibit the transport of colloids. This analysis also does not allow for additional mechanical filtration due to the flow of water through a tortuous pore structure.

Very little modeling has been done on the transport of colloids, complexes, and particulates. Generally, all the remarks presented later in this section for favorable condition 5 should apply qualitatively. The retardation and diffusion parameters will probably be different, however, from those used for simple ions.

Conclusion

The Yucca Mountain site possesses most of the geochemical conditions listed in the statement of favorable condition 2. The pH of water from the vicinity of Yucca Mountain is in the range where most oxide and hydroxide precipitates (particularly actinides) show minimum solubility. The physical properties of the tuffaceous rocks at Yucca Mountain will promote the diffusion of radionuclides into the rock matrix. In addition, the movement of particulates and colloids may be inhibited by the presence of zeolitized bedded tuff beneath the repository horizon. This bedded tuff may act as an efficient filter for the colloids, particulates, and complexes produced by the dissolution of the waste.

The geochemical conditions at Yucca Mountain also promote the sorption of radionuclides. According to estimates of retardation caused only by sorption, the tuffs of Yucca Mountain in the saturated and unsaturated zones will provide significant radionuclide retardation along the expected flow paths to the accessible environment. There is not enough information, however, to determine whether the geochemical conditions at Yucca Mountain will inhibit the formation of particulates or colloids. There are no unusual conditions that would promote the precipitation of waste element solids other than oxides and hydroxides or that would inhibit the formation of aqueous inorganic complexes containing waste elements. The total organic content of

water from the vicinity of Yucca Mountain is very low; no significant quantities of organic complexes with waste elements will form. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

> (3) Mineral assemblages that, when subjected to expected repository conditions, would remain unaltered or would alter to mineral assemblages with equal or increased capability to retard radionuclide transport.

Evaluation

The three mineral assemblages at Yucca Mountain that are likely to be subjected to repository conditions are feldspar-silica, heulandite-smectite, and volcanic glass. Heulandite-smectite and volcanic glass are present in the host rock in quantities of less than 2 percent (Bish et al., 1982). The radionuclide sorptive capacity of the feldspar-silica mineral assemblages located immediately below the repository is low compared with other assemblages (Daniels et al., 1982) and is unlikely to decrease under repository conditions. Heulandite and smectite, concentrated in a zone up to 3 meters (10 feet) thick along the top of the basal vitrophyre of the Topopah Spring Member (Levy, 1984b), might be affected by the minor increase in temperatures. Smectite could reversibly collapse, but would probably regain its cation-exchanging ability when the temperature drops below the boiling point of water (Allen et al., 1984). Calculations of temperature changes due to emplacement of the waste (Johnstone et al., 1984; Morales, 1985) indicate that the maximum extent of the 100°C (212°F) isotherm will be less than about 23 meters (75 feet) vertically above the midplane of the repository, and less than about 28 meters (92 feet) below the repository midplane. The nature and permanence of temperature effects on the sorptive capacity of heulandite are not yet known; however, the potential loss of sorptive zeolites within about 28 meters (92 feet) of the repository midplane represents a very small proportion of total sorptive zeolites that are present in units that underlie the repository (Vaniman et al., 1984).

Studies of natural alteration in the volcanic glass assemblages in the Topopah Spring Member indicate that repository-induced thermal conditions could cause some alteration of the glassy rock to silica-feldspar-zeolite-smectite assemblages (Levy, 1984b). Although the radionuclide sorptive capacity of silica-feldspar assemblages is low, the high sorptive properties of zeolite-smectite assemblages (Daniels et al., 1982) suggest the possibility of enhanced sorptive capacity in the altered rock.

Most of the sorptive zeolites (i.e., clinoptilolite and mordenite) in Yucca Mountain are more than 300 meters (984 feet) below the repository, placing them at a total depth of 650 meters (2,100 feet) (Bish et al., 1984). At this depth, the maximum rock temperature will be about 60°C (140°F) at 10,000 years after waste emplacement (Johnstone et al., 1984). This represents an increase above ambient temperature of about 23°C (73°F). Smyth (1982) has suggested that clinoptilolite and mordenite in Yucca Mountain would be stable to about 100°C (212°F). The small temperature increase could affect the rate at which these minerals recrystallize to less sorptive assemblages including quartz, analcime, alkali feldspar, and possibly clays (favorable condition 1). The 50,000-year duration of the temperature

elevation (Johnstone et al., 1984) is very short compared with the time required for the mineral transformation, estimated as tens of millions of years by Dibble and Tiller (1981). Therefore, it is unlikely that significant zeolite decomposition will take place in 100,000 years.

Conclusion

Under expected repository conditions, the present high radionuclide-retardation capacity of the tuffs at Yucca Mountain is not expected to be significantly degraded and may in fact be increased. Therefore, evidence indicates that this favorable condition is present at Yucca Mountain.

(4) A combination of expected geochemical conditions and a volumetric flow rate of water in the host rock that would allow less than 0.001 percent per year of the total radionuclide inventory in the repository at 1,000 years to be dissolved.

Evaluation

At Yucca Mountain the water available to dissolve the waste forms will be limited by the site characteristics to very small amounts. Estimates of water flux through the unsaturated zone have been presented in Section 6.3.1.1.5, where an upper bound on flux of 0.5 millimeter (0.02 inch) per year has been established for the repository horizon. A value twice the upper bound of 0.5 millimeter (0.02 inch) of 1.0 millimeter (0.04 inch) per year was used in the first two calculations of waste element release rate below. The third calculation presents estimates of release rates for higher flux values that are even more unrealistic.

Two models based on different element-saturation assumptions have been developed that can be used to estimate the dissolution rates of waste elements from a solid waste form at the proposed Yucca Mountain repository (Kerrisk, 1984). The first of these is a saturation-limited dissolution model in which the entire volume of water flowing through the repository is assumed to become saturated with each waste element. The application of this model requires a knowledge of only the water flow rate per unit of waste and the element solubilities. The saturation-limited model is very conservative in that it represents the upper limit on waste-element dissolution rates. It is an upper limit because the physical layout of a repository with large spaces between waste packages would allow much of the water to pass through the repository without becoming saturated with radionuclides. In a realistic model of the dissolution of waste, diffusion of waste elements will limit the concentrations of these elements far from the waste.

The second model is a diffusion-limited dissolution model in which the water present at the waste-water interface is assumed to be saturated with radionuclides; dissolution is limited by diffusion into the water that is flowing past the waste. This model is a significant improvement over the saturation-limited model in that it accounts, in a physically realistic way, for a mechanism to transport waste elements from the solid into the adjacent water. However, in accounting for this process, the model requires information about the geometry of the solid waste, water flow in the surrounding medium, and element diffusivities that can only be estimated at this time.

Some waste elements have high solubilities; cesium is one example. It is unreasonable to assume that the dissolution rates of such elements will be limited by solubility. Elements with high solubilities were assumed to be limited by the dissolution of the bulk waste form (congruent dissolution). The bulk waste form was assumed to dissolve at a fractional rate of 1×10^{-4} per year. This represents a conservative estimate for spent fuel or high-level waste in borosilicate glass (Oversby, 1983; Kerrisk, 1984); this bulk dissolution rate was assumed for these calculations to maximize the effect of solubility on waste-element dissolution rates. Although bulk dissolution rates lower than 1×10^{-4} per year seem likely, their use in this analysis would mask the influence of solubility (Kerrisk, 1984).

Calculations were done for 10 waste elements that represent approximately 99 percent of the spent fuel activity 1,000 years after repository closure. Table 6-26 lists the elements and the solubilities used. Most of the remaining radioactivity not listed in the table comes from several low-solubility elements (e.g., niobium and zirconium); including these elements would not significantly affect the results.

Results from the diffusion-limited dissolution model have been reported for spent fuel and high-level waste (Kerrisk, 1984). This study was conducted for an inventory that contained a 50-50 mixture of spent fuel and high-level waste. The estimate of the repository area needed for waste equivalent to 1 metric ton of heavy metal (MTHM) was based on the decay heat of spent fuel at 10 years after discharge (1,135 watt per MTHM, Croff and Alexander, 1980) and an assumed maximum repository thermal loading of 10 watts per square meter. This gives 114 square meters (1,227 square feet) for each MTHM. With a very conservative flux estimate of 1 millimeter (0.04 inch) per year, a water flow of 114 liters (30 gallons) would pass through the area of 114 square meters (1,227 square feet) per year. This would represent the conditions for the maximum dissolution rate that would be calculated by the saturation-limited model. For the diffusion-limited model, the spent fuel disposal container was assumed to be 0.25 meter (0.82 foot) in radius and 4.5 meters (15 feet) long and to contain 3 MTHM; the high-level waste disposal container was taken to be 0.16 meters (0.5 feet) in radius and 3 meters (10 feet) long and to contain 2 MTHM. For a flux of 1 millimeter (0.04 inch) per year and a 10-percent porosity in the surrounding rock, the pore velocity of water past the waste was estimated at 1×10^{-2} meter (0.03 foot) per year. The apparent diffusivities of waste elements in the water were taken as 1×10^{-10} square meter (1×10^{-9} square foot) per second, including the effects of matrix tortuosity and connectivity. Details of how the results were obtained from the diffusion-limited dissolution model for these parameters and the solubilities listed in Table 6-26 are given by Kerrisk (1984). The ratio of release rate to inventory for a 50-50 mixture of spent fuel and high-level waste glass at 1,000 years after closure is 3×10^{-6} per year, or about three times lower than the 0.001-percent annual limit in the favorable condition. This result does not strongly depend on the water flux. If the bulk fractional dissolution rate is lower than the 1×10^{-4} per year assumed for these results, then the ratio of release rate to inventory will be lower. The results of experiments now under way indicate that the bulk fractional dissolution rate may be much lower than 1×10^{-4} per year (Oversby, 1983).

Table 6-26. Solubilities of elements that are the dominant contributors to spent fuel radioactivity 1,000 years after repository closure[a,b]

Element	Solubility (moles/)
Americium (Am)	1.0×10^{-8}
Plutonium (Pu)	1.8×10^{-6}
Uranium (U)	2.1×10^{-4}
Strontium (Sr)	9.4×10^{-4}
Carbon (C)	large
Cesium (Cs)	large
Technetium (Tc)	large
Neptunium (Np)	3.0×10^{-3}
Radium (Ra)	1.0×10^{-7}
Tin (Sn)	1.0×10^{-9}

[a] The 10 elements listed here contribute about 99 percent of the spent fuel radioactivity 1,000 years after repository closure.
[b] Solubilities at pH 7, oxidizing conditions (Eh = 700 mV, where Eh is the oxidation-reduction potential), and 25°C (77°F) in water that is characteristic of Yucca Mountain (Kerrisk, 1984).

Some idea of the uncertainty of this result can be obtained by comparison with the similar result for the saturation-limited dissolution model. The saturation-limited model gives the ratio of release rate to inventory ratio as 7×10^{-6} per year for a 50-50 waste mixture at 1,000 years after closure. This upper limit for the release rate is about two times higher than the diffusion-limited result, but it is still below the 0.001 percent limit in favorable condition 4.

Oversby and McCright (1984) developed a third model for the release of radionuclides from a spent fuel waste package. Containment barrier corrosion rates are predicted to be very low under the conditions at Yucca Mountain. Data for general corrosion indicate that it will take 67,000 years to corrode away the 1 centimeter- (0.4 inch-) thick waste disposal container. Crevice corrosion rates may be slightly higher under some conditions, but are not expected to significantly affect the time required to degrade and remove the container wall. The expected failure mode for the container is stress corrosion cracking of the heat-effected zone associated with the final closure weld. It is, therefore, expected that for the 67,000 years required to remove the container by uniform corrosion, the waste form dissolution will take place in a perforated but largely intact container.

Oversby and Wilson (1985) have used the model discussed above, together with the data obtained on spent fuel dissolution in Well J-13 water, to obtain an upper limit to the expected release rates for spent fuel under Yucca Mountain conditions. They assumed bare spent fuel in a waste disposal container that had cracks in the closure weld that allowed water to collect in the container. Water was assumed to flow preferentially into the vertical emplacement holes and through the failed containers. Neither of these conditions is expected to occur; however, the purpose of the calculations was to obtain an upper limit to release rates, and for this purpose the assumptions are reasonable.

The upper limits to release rates calculated by Oversby and Wilson (1985) are as follows:

1. For uranium, actinides, and other elements controlled by the dissolution rate of the matrix, the release rate is 6.4×10^{-8} per year.

2. For elements contained partly in the pellet-cladding gap, such as cesium, there is a pulsed release followed by a gradual decrease in release until matrix dissolution control is achieved. The maximum release rate for the repository ensemble average was calculated to be 5.6×10^{-6} per year during the period when fuel pins were breaching and allowing pulsed release to occur.

3. For carbon-14, there is an initial pulsed release from the oxidized skin on the Zircaloy cladding. Further release should be controlled by the rates of dissolution of cladding and the fuel matrix. For a container failure rate of 0.1 percent per year, the release of carbon-14 would be 3×10^{-6} per year for 1,000 years, decreasing thereafter to very low values.

The data used in the calculations were for 25°C (77°F). The data of Ekland and Forsyth (1978) suggest that there will not be a large increase in dissolution rate of the matrix for the highest temperatures under which liquid water dissolution of spent fuel can occur in a Yucca Mountain repository. Tests of spent fuel in Well J-13 water at elevated temperatures will begin in late 1985. Results of these tests will be used, when available, to revise the estimate of release rates.

The cracked container model developed for spent fuel can also be used to assess glass waste form release rates. In this case the water may be assumed to collect in the open space between the top surface of the glass and the upper closure weld. The exposed surface area of the glass (no allowance for cracking) is 0.27 square meter (2.9 square feet), and the head space volume is 108 liters (28 gallons), giving a ratio of surface area to solution volume (SA/V) of 2.5 per meter. Assuming that enough water could flow through the waste disposal container in a year to replace the entire 108 liters (28 gallons), waste form dissolution under these conditions for 1 year would have a (SA/V)t scaling parameter value of 912.5 days per meter. If a cracking factor of 10 is assumed, the (SA/V)t parameter becomes 9,125. This parameter is obtained by multiplying SA/V by the time, t, of the test. The flux

through the repository horizon that would be needed to make these conditions possible would be 20 millimeters (0.8 inch) per year, a value that is 40 times the current upper bound on flux of 0.5 millimeter (0.02 inch) per year (Section 6.3.1.1.5).

Bazan and Rego (1984) have shown that the normalized release rate of lithium from defense waste processing facility 165-frit glass is less than 0.02 gram per square meter-day in J-13 water at 90°C (1.14°F). They used an SA/V of 50 per meter and test times up to 56 days, giving an (SA/V)t value of 2,800. The release rates measured by Bazan and Rego (1984) were close to constant over the range of 600 to 2,800 in (SA/V)t. Lithium is a very soluble element and should give an upper limit to the degradation rate of the glass matrix and to the release of radionuclides. This assumption is supported by the results of Bibler et al. (1984) on 165-frit glass in Well J-13 water.

The scaling-parameter value of 9,125 obtained under the assumptions listed above is outside the range of the present data of Bazan and Rego (1984), but within reach in future experiments. Assuming that the previously established trend continues to be valid up to 9,125 days per meter, a release rate of less than 0.02 gram per square meter per day, or 20 grams (0.7 ounce) per year, would be expected. The weight of glass in the waste disposal container is 1.7×10^6 grams (3,800 pounds), so the release rate would be slightly over 1 part in 100,000. However, the flow rate of water used in these assumptions was 40 times larger than the upper bound presented in Section 6.3.1.1.5. Under the upper bound on flux, the calculated release should be spread over 40 years and be well below the limit of 1 part in 100,000 per year.

Bates and Gerding (1985) have conducted glass release rate tests using a flow rate that is equivalent to a repository flux of 8 millimeters (0.3 inch) per year. They use a cylinder of glass capped with perforated stainless steel to simulate a degraded waste disposal container. Water is delivered by slow dripping onto the top of the specimen at the rate of one drop every 3 days. Release rates based on weight loss after 26 weeks at 90°C (190°F) were 0.5 gram per square meter. Rates based on lithium release were similar, while those for uranium were lower. Scaling this release rate to the free top surface of a glass waste disposal container (0.27 square meter (2.9 square feet) x 10 for cracking) and a 1-year release time, the total release would be 2.7 grams (0.1 ounce). This corresponds to a release rate of 1.6×10^{-6} per year from the glass. If the Bates and Gerding (1985) data are adjusted to a flux of 0.5 millimeter (0.02 inch) per year, the release rate would be 1×10^{-7} per year.

Conclusion

Because of the relatively benign geochemical setting and the low flux of water in the unsaturated zone, it is expected that, for a repository at Yucca Mountain, less than 0.001 percent per year of the total radionuclide inventory 1,000 years after permanent closure would be dissolved. If the presence

of intact cladding on some of the spent fuel and intact waste disposal containers for both waste forms are considered in the calculations, the release rates are expected to be very much lower. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

(5) Any combination of geochemical and physical retardation processes that would decrease the predicted peak cumulative releases of radionuclides to the accessible environment by a factor of 10 as compared to those predicted on the basis of groundwater travel time without such retardation.

Evaluation

Geochemical and physical retardation processes include (1) chemical adsorption of radionuclides onto host minerals, (2) flow governed by the matric potential, and (3) the diffusion and dispersion of radionuclides due to fractures and geometrical effects.

Most of the radionuclides listed in 40 CFR Part 191 (1985) will chemically adsorb to the tuffs of Yucca Mountain. Retardation factors for these radionuclides, as determined from equilibrium batch experiments (Daniels et al., 1982), range from a low of approximately 1 for technetium-99 to almost 1 million for radium-226. All the radionuclides studied, except for technetium-99, have retardation factors well in excess of 10, and for porous flow, the effective velocity of radionuclides is found by dividing the flow rate by the retardation factor. Except for technetium-99, geochemical adsorption will therefore greatly delay the arrival of the peak total radioactivity to the accessible environment. There is also considerable variation in the retardation factor values from one stratigraphic unit to another, and this will act to separate the various radionuclides much like a chromatographic column. This separation will result in a spreading out or stretching in time of the cumulative release, and hence, a reduced rate of release to the accessible environment (Travis et al., 1984). This effect is expected to apply along the entire path to the accessible environment, not just in the unsaturated zone.

The potential host rock at Yucca Mountain is a fractured, unsaturated tuff. The effect of fractures on flow and transport is not fully understood at this time, especially for the unsaturated zone. Preliminary analysis of water flow in fractures (Travis et al., 1984) indicates that narrow-aperture cracks will not be able to transmit water very far because of strong matric potential. Therefore, the flux of 0.5 millimeter (0.02 inch) is expected to be transported predominantly in the matrix. If flux conditions do allow fracture flow in the unsaturated region (because of the presence of wide cracks in units with high saturation), diffusion out of cracks into the rock matrix will retard the progress of radionuclides by at least a factor of 100 (Travis et al., 1984). Diffusion from fractures in the saturated zone could also retard transport compared with transport in fractures without diffusion (see favorable condition 2, part (b)).

A conservative numerical evaluation for this favorable condition was made as follows. A representative path from the disturbed zone to the water table for an estimated unsaturated zone flux of 0.5 millimeter (0.02 inch) per year was chosen. It has a travel time of 43,265 years, which is the mean

of the travel-time distributions given in Section 6.3.1.1.5. The waste disposal containers were assumed to fail at 1,000 years and the entire inventory was assumed to be instantaneously available for dissolution and transport. The peak cumulative release, neglecting retardation of any radionuclide, would then be at about 44,000 years and would be the entire inventory of 1.2×10^5 curies per 1,000 metric tons of heavy metal (MTHM) (Croff and Alexander, 1980). Alternatively, using retardation factors calculated from representative values of sorption ratios from tables 6-23a and 6-23b, the peak cumulative release would be expected at 44,000 years after closure and would consist of technetium-99, iodine-129, and carbon-14. At 44,000 years the technetium-99 inventory is 1.05×10^4 curies per 1,000 MTHM, the carbon-14 inventory is less than 10 curies per 1,000 MTHM, and iodine-129 inventory is 31 curies per 1,000 MTHM. This calculation shows that geochemical retardation alone will decrease the peak cumulative release by a factor of 11.4. Other retardation mechanisms such as matrix diffusion and dispersion have been neglected. This calculation demonstrates only that retardation processes at Yucca Mountain are capable of decreasing peak releases by at least the factor of 10 specified in the favorable condition. Because of the numerous conservative simplifying assumptions made in the calculation, it does not represent a prediction of the likely magnitude of future releases.

Conclusion

Chemical adsorption, an extremely low water flux, and radionuclide diffusion into the rock matrix all combine to decrease the predicted peak cumulative radionuclide release to the accessible environment by at least a factor of 10 as compared with predictions based on ground-water travel time without such retardation. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

6.3.1.2.4 Potentially adverse conditions

(1) Ground-water conditions in the host rock that could affect the solubility or the chemical reactivity of the engineered-barrier system to the extent that the expected repository performance could be compromised.

Evaluation

The pre-waste-emplacement water chemistry in the host rock is not known, because water samples from the unsaturated zone of the Topopah Spring Member have not yet been obtained. However, it is assumed to be similar to the composition of samples obtained from below the water table in drill holes at Yucca Mountain (Daniels et al., 1982), because water in the saturated zone includes water that was formerly in the unsaturated zone. The ground-water samples have similar chemical compositions and, when taken as a group, are similar to water taken from Well J-13 (approximately 6.5 kilometers (4 miles) southeast of Yucca Mountain). At Well J-13, the Topopah Spring Member lies

below the water table and is the producing horizon for the well. Because of the relative uniformity of ground-water chemistry obtained from drill-hole samples, and the similarity of the ground water to that of J-13 water, the J-13 water has been used as the reference water for the repository horizon. Samples of water from the unsaturated tuffs at Yucca Mountain will be obtained when the exploratory shaft is constructed. The reference water composition will then be revised, and the potential effects of any differences between the waters drawn from the unsaturated zone and Well J-13 will be evaluated.

As shown in Table 6-27, the major components of water from Well J-13 are sodium, silicon, and bicarbonate ion, with lesser amounts of calcium, potassium, magnesium, sulfate, nitrate, chlorine, and fluorine. All other elements are present in concentrations less than 0.2 milligram per liter. The pH of the water is nearly neutral. When J-13 water was reacted with Topopah Spring tuff at 90 and 150°C (190 and 300°F), only very slight changes in anion concentrations in solution occurred (Knauss et al., 1984). The principal changes in chemistry of the water were an increase in silicon concentration to a level just below the solubility limit of cristobalite, a decrease in the concentrations of magnesium, calcium, and the bicarbonate ion due to precipitation of calcium-magnesium carbonate, at the higher temperatures, and an increase in aluminum concentration (to approximately 0.5 milligram per liter at 90°C). Results obtained using samples of the Topopah Spring Member from drill cores USW G-1, USW GU-3, USW G-4, and UE-25h#1 were consistent with those obtained from surface-outcrop material collected at Fran Ridge. This suggests that lateral variation in the chemistry of the tuff is not likely to cause major variations in the host rock water chemistry (Oversby, 1983, 1985).

Drill-core samples of Topopah Spring tuff were tested for the presence of any readily soluble material in or on the rocks. Such material is found on outcrop samples in arid climate zones and has been shown to be present at the extreme southwest spur of Yucca Mountain and Fran Ridge near Yucca Mountain (Knauss et al., 1984; Oversby and Knauss, 1983). The USW holes were drilled using drilling fluids that might have removed soluble salts; however, the materials tested from UE-25h#1 were obtained by air drilling horizontally into the side of Fran Ridge and provide a good test of whether the soluble material can be expected to occur at some distance from the surface. The sample obtained from 24 meters (78 feet) into the air-drilled hole was the closest to the original outcrop surface. None of the samples tested was found to contain any evidence for significant amounts of readily soluble material that could increase the anion content of J-13 water. This result strongly suggests that the presence of soluble salts is a surface evaporation phenomenon and that such materials are unlikely to be present at the depth of the repository. This topic will be further investigated by the examination of cuttings from the unsaturated zone characterization holes (UZ series).

To determine the effects of water chemistry on expected repository performance, one must consider the potential rates and mechanisms for the corrosion of the waste disposal containers, and the dissolution rates of the waste forms. The reference container material is austenitic stainless steel.

Table 6-27. Chemistry of J-13 well water[a,b]

Component	Mean concentration (mg/L)	Standard deviation[c]
Cations		
Magnesium (Mg)	2.17	0.22
Manganese (Mn)	0.16	0.02
Silicon (Si)	30.7	2.3
Iron (Fe)	0.001	0.020
Strontium (Sr)	0.09	0.06
Barium (Ba)	0.021	0.014
Vanadium (V)	0.023	0.016
Titanium (Ti)	0.000	0.013
Calcium (Ca)	12.2	1.2
Lithium (Li)	0.16	0.16
Potassium (K)	6.8	2.0
Aluminum (Al)	0.003	0.011
Sodium (Na)	51.7	3.5
Anions[d]		
Fluorine (F)	2.0	
Chlorine (Cl)	6.4	
Phosphate (PO_4)	0.1	
Nitrite (NO_3)	9.6	
Sulphate (SO_4)	18.2	
Alkalinity as HCO_3	135	

[a] Data from Daniels et al. (1982).
[b] pH = 7.1.
[c] Standard deviations about mean for cation data are for well water collected over six-month intervals.
[d] Anion data are averages of two samples taken six months apart.

During the first 1,000 years after emplacement, uniform corrosion of this material in the repository environment is expected to cause the loss of less than 0.1 centimeter (0.04 inch) of metal from the wall of the container, which is 1 centimeter (0.4 inch) thick. The J-13 water chemistry both before and after hydrothermal reaction with Topopah Spring tuff has low concentrations of elements like fluorine and chlorine, which reduces the likelihood of pitting or crevice corrosion in the austenitic stainless steel. The relatively benign water chemistry is also unlikely to enhance any stress-assisted corrosion. Thus, there are no known ground-water conditions at Yucca Mountain that are expected to compromise the performance of the metal barrier

(McCright et al., 1983; Oversby and McCright, 1984; Oversby, 1985). The possibility exists, however, that dehydration-rehydration effects, produced as the waste disposal containers go through the elevated temperature phase, may increase the salt concentrations in the ground water near the containers, which could increase the chance for their corrosion. This scenario is discussed in more detail in Section 6.3.1.3.4.

The testing of borosilicate-glass waste forms in J-13 water, both with and without tuff present, is in progress. The results of testing with experimental samples of glass (PNL 76-68 glass) indicate that the presence of tuff diminishes the dissolution rates of the glass (Oversby, 1983). Dissolution rates of defense-high-level-waste glass in J-13 water without tuff are substantially lower than those found in deionized water (Bazan and Rego, 1984). Thus, the water conditions expected in the host rock are not expected to adversely affect the performance of borosilicate glass waste forms. On the contrary, the presence in the water of silicon leached from the host rock appears to decrease the dissolution rate of the glass matrix (Oversby, 1983).

Spent fuel has been tested in deionized water and in J-13 water at 25°C (77°F) (Wilson and Oversby, 1985). These results show that there is no increase in spent fuel dissolution and degradation in J-13 water over that in deionized water. On the contrary, there is less evidence for attack of the fuel at grain boundaries in the J-13 water, less total mobilization of fuel components (based on the inventory of elements found plated out on the reaction vessel plus those in solution), and lower solution concentrations for most actinides. Uranium is more soluble in J-13 water than in deionized water, with an apparent solubility of approximately 5 parts per million, based on the highest concentrations observed during six months of testing. The higher solubility of uranium in J-13 water is due to the bicarbonate content of the water. The results obtained are in agreement with those found by other workers using spent fuel in waters of similar compositions (Johnson et al., 1981). On the basis of these results, it is considered likely that the expected water compositions in the repository will not compromise the performance of spent fuel waste forms.

Conclusion

Ground-water conditions in the Topopah Spring Member of the Paintbrush Tuff at Yucca Mountain are expected to be such that no changes in the solubility and the chemical reactivity will degrade the engineered barrier system, and no degradation of repository performance is expected. Preliminary results for both the metal waste disposal container and for the waste forms show no detrimental effects due to host-rock water chemistry. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(2) Geochemical processes or conditions that could reduce the sorption of radionuclides or degrade the rock strength.

Evaluation

The zeolites clinoptilolite and mordenite are high-silica zeolites found at Yucca Mountain. They are metastable with very slow reaction rates. The

aluminum-to-silicon ratio for these zeolites is slightly variable but is generally near 3-to-15 (Caporuscio et al., 1982). For the sodium end member of such a zeolite the reaction to albite can be written:

$$Na_3Al_3Si_{15}O_{36} \cdot 12H_2O = 3NaAlSi_3O_8 + 6SiO_2 + 12H_2O \qquad (6-3)$$

(zeolite)   (feldspar)
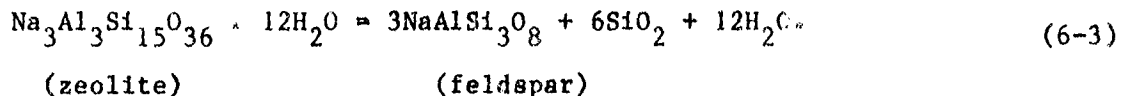
Because clinoptilolite and mordenite contain abundant silica, when they break down, usually to feldspars or analcime, silicon dioxide is also produced. From this reaction, it can be noted that if the chemical potential of silicon dioxide is high, the reaction will tend to move toward the left, forming a zeolite mineral. If the chemical potential of silicon dioxide is low, there will be a tendency to form feldspar, or analcime if it is more stable.

Glass and cristobalite are metastable phases in tuff environments at Yucca Mountain and produce higher chemical potentials of silicon dioxide than does the stable silica mineral, quartz. Clinoptilolite and mordenite in tuffs form as alteration products of glass (Hay, 1978) and at Yucca Mountain tend to coexist with cristobalite but not with major amounts of quartz (Waters and Carroll, 1981; Caporuscio et al., 1982).

Successful laboratory syntheses of clinoptilolite have used starting materials that produce a high chemical potential for silicon dioxide (Hawkins, 1981; Chi and Sand, 1983). Fluid from 150°C (300°F) hydrothermal experiments with clinoptilolite bearing samples from the tuffaceous beds of Calico Hills at Yucca Mountain contained 470 milligrams per liter silicon dioxide, which is well above the concentration that would be in equilibrium with quartz (Wolfsberg et al., 1983). Finally, calculations using estimated thermodynamics data for Na and K-clinoptilolites and mordenites (Daniels et al., 1983) indicate that the silica concentration in solution for the zeolite transition to feldspar at temperatures between 25 and 200°C (77 and 390°F) is near that for cristobalite saturation.

These observations lead to the conclusion that clinoptilolite and mordenite are metastable minerals at Yucca Mountain. With the gradual transition of the glass and cristobalite to quartz, the clinoptilolite and mordenite become unstable and recrystallize over geologic time periods to less sorptive minerals. However, as already discussed under favorable condition 3, above, it is very unlikely that this transition will be sufficiently rapid to affect repository performance.

Conclusion

The sorptive zeolites found in Yucca Mountain (heulandite, clinoptilolite, and mordenite) are metastable, with very slow reaction rates. Through time, the zeolites might begin to recrystallize to less sorptive minerals.

However, as discussed under favorable condition 3, very little reaction is expected in the next 100,000 years. Sorptive properties and host-rock strength are not expected to be reduced by geochemical processes occurring at Yucca Mountain. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(3) Pre-waste-emplacement ground-water conditions in the host rock that are chemically oxidizing.

Evaluation

The potential host rock at Yucca Mountain lies above the water table and is in the densely welded portion of the Topopah Spring Member of the Paint-brush Formation. Pores in the rock will be partially filled with water and partially filled with air because of the unsaturated conditions. Consequently, the water can be expected to contain dissolved oxygen up to a level of 8.1 parts per million, which is the solubility of oxygen at 25°C (77 °F) and 1 atmosphere (Linke, 1965). There are no major mineral components in the potential host rock that can be expected to react with the dissolved oxygen. However, the reaction of the trace minerals in the rock (e.g., biotite, amphibole, ilmenite, and magnetite) that contain ferrous iron could consume some of the dissolved oxygen.

Although the proposed repository is in an oxidizing environment, there are some factors that could effectively reduce the amount of oxygen reaching the emplaced waste. Reductions in the oxidation state of the water could result from interaction with the austenitic stainless steel of the waste disposal containers. In addition, under mildly oxidizing conditions this steel should develop a protective oxide film that would limit further corrosion of the container (McCright et al., 1983). Thus, the pre-waste-emplacement oxidizing conditions may prolong the lifetime of the waste disposal container.

The release of radionuclides from vitrified waste in the Yucca Mountain environment is expected to be controlled by the matrix solubility of the glass, and to occur at levels less than 1 part in 100,000 per year of the inventory at 1,000 years after closure (Oversby, 1983). The pre-waste-emplacement oxidizing conditions are not expected to adversely affect the rate of release from glass waste forms. As mentioned above, the oxidation state of the water in contact with the waste forms may have been lowered by interactions with the metal container. Water contact with spent fuel may also be buffered by reaction with the Zircaloy cladding of the fuel, a reaction that could cause further lowering of the oxidation state of the water.

Oxidizing conditions in water that contacts spent fuel waste forms could produce two potentially adverse effects. First, the solubility of spent fuel in an oxidizing environment will generally be greater than that in a reducing environment (Lemire and Tremaine, 1980). This could lead to a larger release of radioactive elements from the waste disposal container under oxidizing conditions than under reducing conditions if all other factors are the same. Second, the presence of oxidizing conditions might adversely affect the lifetime of the Zircaloy cladding if the uranium dioxide were to become oxidized and cause stress rupture of the cladding.

Conclusion

The ground-water conditions at Yucca Mountain are expected to be chemically oxidizing. As discussed above, this condition could be altered after the emplacement of waste disposal containers and is not expected to cause serious problems with respect to the solubility or chemical reactivity of the engineered barrier system. Nonetheless, oxidizing conditions are expected in the pre-waste-emplacement environment. Therefore, the evidence indicates that this potentially adverse condition is present at Yucca Mountain.

6.3.1.2.5 Evaluation and conclusion for the qualifying condition on the postclosure geochemistry guideline

Evaluation

Identified geochemical processes involving mineralogic reactions have been inoperative at Yucca Mountain during the Quaternary Period or have, during this period, occurred at low enough rates and affected small enough areas that their continuation over the next 100,000 years is unlikely to affect the ability of the geologic repository to isolate waste. The pH of the water from the vicinity of Yucca Mountain is in the range where the oxide and hydroxide precipitates for most radioactive elements (particularly actinides) show minimum solubility. The matrix properties of the host rock and surrounding units favor diffusion, (favorable condition 2, part (b)), and the geochemical conditions at Yucca Mountain promote the sorption of radionuclides. The total organic content of water from the vicinity of Yucca Mountain is very low; no significant quantities of organic complexes containing waste elements are likely to form. The movement of particulates and colloids may be greatly inhibited by the presence of zeolitized tuff, which occurs beneath the repository horizon and is expected to have few fractures. Present knowledge indicates that the sorptive capacity will not significantly decrease and could even increase over the next 100,000 years. Although the sorptive zeolites (clinoptilolite and mordenite) may break down over geologic time, very little reaction is expected in the next 100,000 years. The expected geochemical conditions and water flux at Yucca Mountain will allow less than 0.001 percent per year of the total radionuclide inventory in the repository at 1,000 years after permanent closure to be dissolved. There are several retardation processes that will decrease predicted peak cumulative radionuclide release to the accessible environment by a factor of at least 100 as compared with predictions based on ground-water travel time without such retardation.

Solubility and chemical reactivity of the engineered barrier system under expected repository conditions in the Topopah Spring Member at Yucca Mountain allow satisfactory performance under expected repository conditions. Changes in the oxidation-reduction state of the water due to interaction with the austenitic stainless steel of the waste disposal container or with the Zircaloy cladding of spent fuel rods could mitigate the consequences of the chemically oxidizing pre-waste-emplacement ground-water conditions.

Conclusion

The present and expected geochemical characteristics of the Yucca
Mountain site provide reasonable expectation that radionuclide releases from
the engineered barrier system and to the accessible environment will meet the
applicable limits and performance objectives. The engineered barrier system
is expected to meet performance objectives for containment and isolation
because of the benign chemistry of the unsaturated emplacement environment
and the extremely low water flux. Therefore, the evidence does not support a
finding that the site is not likely to meet the qualifying condition for
geochemistry (level 3).

6.3.1.2.6 Plans for site characterization

A number of tests are planned to improve the understanding of geo-
chemical conditions and processes at Yucca Mountain. Analysis of rock
samples collected during construction and from lateral coring in the
exploratory shaft and in drifts in the in situ test facility will provide
data to better establish the vertical and lateral mineralogical and geo-
chemical variability in the tuffaceous rocks at Yucca Mountain. Perched
water, fracture-bound water, and any other mobile water in the unsaturated
zone will be sampled, monitored, and analyzed to understand the types and
magnitudes of chemical reactions occurring within the unsaturated zone. In
addition, large blocks of rock will be obtained at various depths during
construction of the exploratory shaft for chlorine-36 analyses of pore-water
age. This analysis will provide supporting data for estimates of flow rates
and travel times in the repository horizon.

A diffusion test is also planned during the in situ phase of testing.
This test will be used to evaluate and confirm the diffusion processes and
rates in the unsaturated Topopah Spring welded unit and the Calico Hills non-
welded unit. Results of this test will aid in establishing confidence in the
radionuclide retardation capability of the host rock.

6.3.1.3 Rock characteristics (10 CFR 960.4-2-3)

6.3.1.3.1 Introduction

The qualifying condition for this guideline is as follows:

The present and expected characteristics of the host rock and
surrounding units shall be capable of accommodating the thermal,
chemical, mechanical, and radiation stresses expected to be induced
by repository construction, operation, and closure and by expected
interactions among the waste, host rock, ground water, and engineered
components. The characteristics of and the processes operating

within the geologic setting shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements set forth in 10 CFR 60.113 for radionuclide releases from the engineered barrier system using reasonably available technology.

Postclosure rock characteristics are important to the long-term isolation capability of the host rock. The mining operation during repository construction and the heat generated by the emplaced waste must not lead to conditions that would significantly diminish the ability of the site to contain and isolate the waste. If extensive changes in the host rock were induced, new pathways or barriers for radionuclide migration from the repository could result, and the isolation capabilities of the host rock could be impaired. The objective of the postclosure rock characteristics guideline is to ensure that the present and expected characteristics of the host rock and surrounding units can accommodate the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure and by expected interactions among the waste, the host rock, the ground water, and the engineered barrier system.

The postclosure rock characteristics guideline consists of two favorable conditions, three potentially adverse conditions, and one qualifying condition. The evaluations reported below are summarized in Table 6-28.

6.3.1.3.2 Data relevant to the evaluation

Summary of available data

The stratigraphic section at Yucca Mountain is composed of a sequence of welded and nonwelded tuffs; some strata are devitrified or altered, and some remain vitric (Scott and Castellanos, 1984). The strata have been subjected to varying amounts of mineral alteration, as described by Bish et al. (1984). The densely welded devitrified portion of the Topopah Spring Member of the Paintbrush Tuff at Yucca Mountain has been selected as the potential host rock (Johnstone et al., 1984) after an area-to-location screening evaluation (Sinnock and Fernandez, 1982). Studies by Mansure and Ortiz (1984) and Nimick and Williams (1984) have provided estimates of the vertical and lateral extent of the potential host rock. The relevant data for analyzing the impact of rock characteristics on waste containment and isolation include the geologic, mineralogic, physical, thermal, and mechanical attributes of the relevant rock types. The special considerations involved in disposal of waste in the unsaturated zone have been reviewed (Roseboom, 1983). The geologic attributes include the thickness and lateral extent of units (Nimick and Williams, 1984) and structural features such as fracturing and stress state. The potential host rock at Yucca Mountain is highly fractured but many of the fracture attributes, such as orientation, frequency, length, and aperture, have not yet been measured (Spengler et al., 1979, 1981; Spengler and Chornack, 1984; Maldonado and Koether, 1983). Preliminary measurements of in situ stresses have been made (Healy et al., 1982). Bish et al. (1984)

Table 6-28. Summary of analyses for Section 6.3.1.3; postclosure rock characteristics (10 CFR 960.4-2-3)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITIONS	
(1) A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility to ensure isolation.	The evidence indicates that this favorable condition is not present at Yucca Mountain: the host rock is sufficiently thick and laterally extensive to ensure isolation; however, significant lateral flexibility cannot be claimed until site-characterization data are available.
(2) A host rock with a high thermal conductivity, a low coefficient of thermal expansion, or sufficient ductility to seal fractures induced by repository construction, operation, or closure or by interactions among the waste, host rock, ground water, and engineered components.	The evidence indicates that this favorable condition is present at Yucca Mountain: the host rock possesses a low thermal expansion coefficient; calculated thermal and mechanical behavior of the host rock suggests no adverse response to be expected.
POTENTIALLY ADVERSE CONDITIONS	
(1) Rock conditions that could require engineering measures beyond reasonably available technology for the construction, operation, and closure of the repository, if such measures are necessary to ensure waste containment or isolation.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: no rock conditions identified to date are expected to require extraordinary engineering measures to ensure waste containment or isolation.
(2) Potential for such phenomena as thermally induced fractures, the hydration or dehydration of mineral components, brine migration, or other physical, chemical, or radiation-related phenomena that could be expected to affect waste containment or isolation.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: the potential host rock is expected to be physically and chemically stable; calculations indicate that thermally induced fracturing would be minor and would not be expected to affect waste containment or isolation.

Table 6-28. Summary of analyses for Section 6.3.1.3; postclosure rock characteristics (10 CFR 960.4-2-3) (continued)

Condition	Department of Energy (DOE) finding
(3) A combination of geologic structure, geochemical and thermal properties, and hydrologic conditions in the host rock and surrounding units such that the heat generated by the waste could significantly decrease the isolation provided by the host rock as compared with the pre-waste-emplacement conditions.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: no combination of host-rock properties and conditions has been identified that would be expected to cause a decrease in isolation capability because of the heat load.
QUALIFYING CONDITION	
The present and expected characteristics of the host rock and surrounding units shall be capable of accommodating the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure and by expected interactions among the waste, host rock, ground water, and engineered components. The characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements set forth in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.	Existing information does not support the finding the site is not likely to meet the qualifying condition (level 3): the characteristics of the host rock and surrounding units are expected to permit compliance with containment or isolation requirements. Available data suggest rock characteristics are not expected to compromise performance of the waste package.

provide the bulk mineralogic data for various stratigraphic layers. A preliminary assessment of the potential for halide concentrations in the ground water of the repository environment is provided (Morales, 1985). Preliminary investigations of the corrosion of the stainless steel waste disposal containers due to the gamma radiolysis of water have been made (DOE/NVO, 1985). The effect of the heat generated by the waste container on the immediate environment around the repository horizon has been evaluated by Stein et al. (1984).

Tillerson and Nimick (1984) have described relevant physical properties including density and porosity, and heat capacity, thermal conductivity, and thermal expansion for comparison with the properties of other rock types (DOE, 1984a,b; Tuma, 1976; Clark, 1966). Mechanisms that may alter host-rock permeability have been investigated (Braithwaite and Nimick, 1984; Wollast, 1967; White et al., 1980; McVay, 1982; Moore et al., 1984). Temperature and pressure effects are yet to be investigated although limited data are available for similar rock types (Zimmerman, 1983). The temperatures expected in the repository have been calculated (Morales, 1985) and the effects have been investigated of elevated temperatures on tuff mineralogy (Bish, 1981; Bish et al., 1982; Koster van Groos, 1981; Lappin, 1980a), water movement (Stein et al., 1984; Mondy et al., 1983), and ground-water chemistry (Oversby 1983; Erdal et al., 1979; Johnstone and Wolfsberg, 1980; Daniels et al., 1982). Ground-water flux through the repository has also been estimated (Wilson, 1985). The mechanical properties needed for repository design include the elastic modulus, Poisson's ratio, cohesion, angle of internal friction, and tensile strength for intact material and such fracture properties as shear and normal stiffness, cohesion, and the coefficient of friction. The dependence of these properties on water content, confining stress, and temperature is under investigation. Preliminary designs for borehole and repository plugging and sealing have been prepared (Fernandez and Freshly, 1984; Jackson, 1984).

Assumptions and data uncertainties

Rock conditions that are influenced by geochemical and hydrologic conditions are discussed in the geochemistry guideline (Section 6.3.1.2) and the geohydrology guideline (Section 6.3.1.1). Changes in rock attributes during the operation of the repository (Section 6.3.3.2) can also be important to the postclosure behavior of the repository. This guideline addresses the rock conditions after closure and their potential effects on waste containment and isolation. In order to evaluate the effects of heating on the very near, near, and far fields for periods to 50,000 years, various waste emplacement configurations (including the preferred vertical and alternative horizontal configurations), canister loadings (1.6 and 3.3 kilowatts per canister for spent fuel and 2.16 kilowatts per canister for commercial high-level waste), and repository gross thermal loadings (50 to 100 kilowatts per acre) were assumed. Rock properties actually determined for the host rock and surrounding units were used, where available. Where specific properties for a particular unit were not available, the property was estimated by comparison with a similar rock unit. Virtually no data are available on properties of individual fractures or the effects of fractures on rock matrix properties, although experiments to measure such properties are under way in the laboratory and planned for the exploratory shaft.

Conservative assumptions were used in all of the computer analyses reported here. The characteristics of fractures are difficult to model; for these analyses the fractures were modeled as planar, ubiquitous, and non-intersecting. Models are being developed to better understand the influence of fractures. The current models also rely on sequential rather than fully coupled, calculations. Often, averaged properties were used in the evaluations. Whenever possible, average and bounding properties were determined by statistical analysis.

Some geologic uncertainty arises because the data are derived from surface mapping and a limited number of boreholes. Nevertheless, the three-dimensional geologic model of Yucca Mountain is reasonably complete (Nimick and Williams, 1984). The material properties of the stratigraphic units are determined from cores typically 5 centimeters (2 inches) or less in diameter. Because the sample size is small, the known properties are mainly limited to those of the matrix rather than the rock mass. Also because of the small sample size, discontinuities present in the rock mass are not necessarily included in the sample. Some of the thermal and mechanical matrix properties are relatively well known because a large number of samples have been measured. In these instances, the data have been statistically analyzed to yield average values and standard deviations.

Quantitative and qualitative analyses are used in the discussion of the favorable and potentially adverse conditions. The quantitative analyses used computer models to predict the thermal and thermomechanical behavior of the rock units. Qualitative and semiquantitative analyses were used to predict mineralogical responses to the heat emitted by the waste decay, the thickness and lateral extent of the host rock, and the relation of rock characteristics to engineering requirements.

The uncertainty introduced by the computer models is poorly known at present. Evaluations are under way to investigate this uncertainty by comparing the results of different models solving the same problem. The models are also being used to predict and compare the results of specific experiments and field tests.

The preliminary assessment of possible halide concentrations in the repository environment are based on incomplete investigations that will be continued during site characterization, as will the early investigations of radiation-related phenomena.

6.3.1.3.3 Favorable conditions

(1) A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility to ensure isolation.

Evaluation

Four potential emplacement horizons in Yucca Mountain have been evaluated (Johnstone et al., 1984), and the unsaturated densely welded devitrified portion of the Topopah Spring Member has been selected as the preferred

repository horizon. The other three units were also judged to meet
performance requirements for waste isolation, but ranked below the Topopah
Spring Member. These units are the tuffaceous beds of Calico Hills and the
Bullfrog and Tram members of the Crater Flat Tuff. The ranking criteria
included (1) ground-water travel time, (2) allowable gross thermal loading,
(3) excavation stability, and (4) relative economics. For the unit evalu-
ation, the Topopah Spring Member was limited to the zone containing less than
5 percent lithophysal cavities. At these low percentages, lithophysal
cavities have little effect on the thermomechanical properties of the rock.
At what percentage the lithophysal cavities become a concern will be deter-
mined during site characterization. For planning purposes, the underground
facility has been placed in the relatively lithophysae-free section (less than
15 to 20 percent) that lies above the basal vitrophyre (Mansure and Ortiz,
1984). To date, however, no thermal or mechanical characteristics have been
identified that would make the units below the proposed emplacement horizon
(including the vitrophyre) unacceptable for the placement of waste.

Area 1 on Figure 6-14 is the primary area for locating the underground
facility. It contains relatively few faults and rare fault breccias (Scott
and Bonk, 1984). The surface and subsurface geologic exploration of Yucca
Mountain has concentrated in this area and in the immediately surrounding area
that has a relatively low fault density. Available site data indicate that
rock with acceptable characteristics may be present within areas 2 through 6,
and perhaps even outside these areas (Mansure and Ortiz, 1984; Sinnock and
Fernandez, 1982).

Analysis of the output from a three-dimensional computer graphics model
of Yucca Mountain (Nimick and Williams, 1984) indicates that area 1 contains
approximately 890 hectares (2,200 acres) although minor faults and breccia and
blocks rotated to steep dips may occupy some of the area; approximately
749 hectares (1,850 acres) of area 1 are potentially usable on the basis of
the disqualifying condition for erosion, which requires a 200-meter (656-foot)
overburden. The present estimates of waste inventories and the current
repository design concepts (Mansure and Ortiz, 1984) require 616 hectares
(1,520 acres) for a repository. Area 2 (Figure 6-14), a primary area for
extending the underground facility from area 1, covers approximately 910 hec-
tares (2,250 acres) and is similar to area 1 in fault density. Data for area
2 are limited to those obtained from surface mapping and extrapolation from
drill-hole data obtained mainly in and around area 1. If extension of the
underground facility from area 1 is required to provide lateral flexibility,
additional geologic information may be obtained as part of site characteriza-
tion to determine how much of this area is usable. Area 3 covers approx-
imately 162 hectares (400 acres). Small portions of this area might not pass
the disqualifying condition for erosion which requires 200 meters (656 feet)
of overburden. Area 4 covers approximately 607 hectares (1,500 acres) and
also may have rock characteristics similar to the other areas, but fewer data
exist for this area, and it is farther from the primary repository area. As
in area 3, portions of area 4 might not pass the disqualifying condition for
200 meters (656 feet) of overburden. Area 5 contains about 202 hectares
(500 acres), and area 6 contains 1,072 hectares (2,650 acres). Area 6 has a
very complex fault structure with steeply dipping faults, and part of it may
not meet the 200-meter (656-foot) overburden requirement. Flexibility in
lateral extent cannot be demonstrated at this time because the data for areas
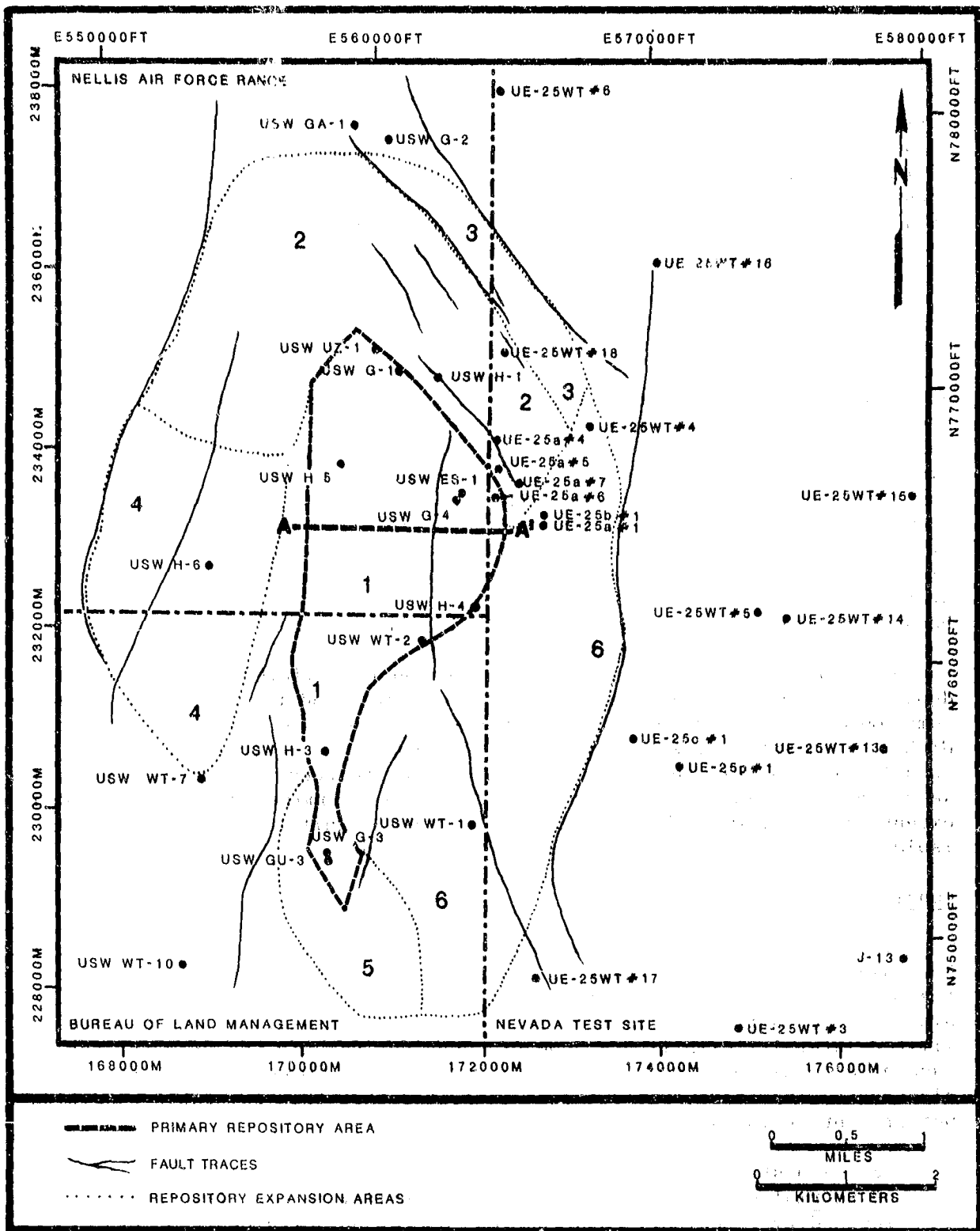2 through 6 are limited.

Figure 6-14. Potential repository expansion areas. Area 1 is the primary area for the underground facility. See text for detailed discussion of areas 1, 2, 3, 4, 5, and 6. Cross section A-A' is shown on Figure 6-16. Modified from Mansure and Ortiz (1984).

The basic requirements for the thickness of the geologic section are (1) the presence of sufficient overburden to ensure a low probability of uncovering the waste by erosion and (2) sufficient thickness of host rock to provide the volume envelope required for the underground facility. The thickness of the erosional barrier at Yucca Mountain is more than 300 meters (984 feet) over about 50 percent of area 1. Figure 6-15 shows the thickness of the overburden above the midplane of the repository envelope, which is conservatively assumed to be 45 meters (150 feet) thick (Mansure and Ortiz, 1984). To date, exploration in area 1 has revealed sufficient thickness of the potential host rock to isolate the waste.

Figure 6-16 is a cross section along approximately A-A' in Figure 6-14 showing the possible location of the underground facility. The potential repository host rock is the lower portion of the Topopah Spring Member, designated Tpt on this figure. A three-dimensional model of area 1 that incorporates surface and subsurface data (Nimick and Williams, 1984) was used to determine that the host rock is sufficiently thick to provide flexibility in selecting the depth of the underground facility. For most of the usable portion of area 1, the thickness of the potential host rock is over three times the thickness required to contain the repository. Mansure and Ortiz (1984) show that the approximate thickness of the preferred host rock is on the order of 100 to 175 meters (330 to 575 feet) within area 1. Also shown in Figure 6-16 are the projected underground locations of some faults identified at the surface. These faults do not restrict the location of a repository, because the simple presence of a fault is not necessarily detrimental to a repository located in the unsaturated zone; they could, in fact, be advantageous (Roseboom, 1983). There is no reason to believe that constraints on depth, configuration, and location of the underground facility will in any way compromise the potential isolation performance of the Yucca Mountain site. With the low water flux that is expected through the repository, and the more than 185 meters (610 feet) of unsaturated rock between the repository and the water table, possible constraints resulting from limited vertical or lateral extent of the host rock are unlikely to have significant effects on the isolation provided by the thick unsaturated zone.

Conclusion

The potential host rock within the primary repository area at Yucca Mountain is sufficiently thick to provide significant vertical flexibility in the placement of the repository to insure isolation. The potential host rock also provides sufficient lateral extent to insure isolation, but provides only limited lateral flexibility. However, considering only the primary area, this favorable condition cannot be claimed for lateral flexibility in repository placement. Therefore, the evidence indicates that this favorable condition is not present at Yucca Mountain.

(2) A host rock with a high thermal conductivity, a low coefficient of thermal expansion, or sufficient ductility to seal fractures induced by repository construction, operation, or closure or by interactions among the waste, host rock, ground water, and engineered components.
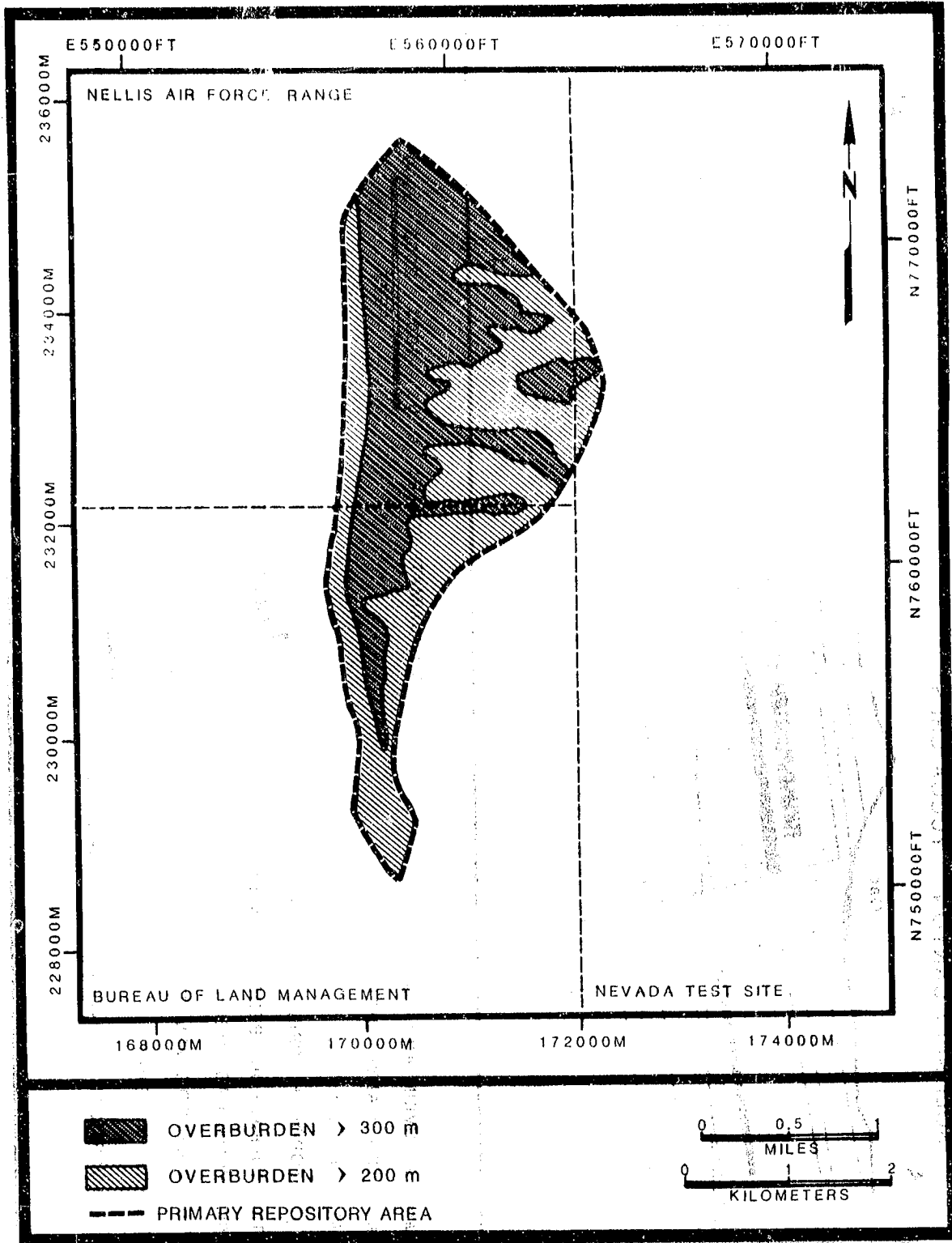
Figure 6-15. Approximate outline of primary repository area showing areas with greater than 200 and 300 meters (656 and 984 feet) of overburden above the midplane of the repository. Modified from Mansure and Ortiz (1984).
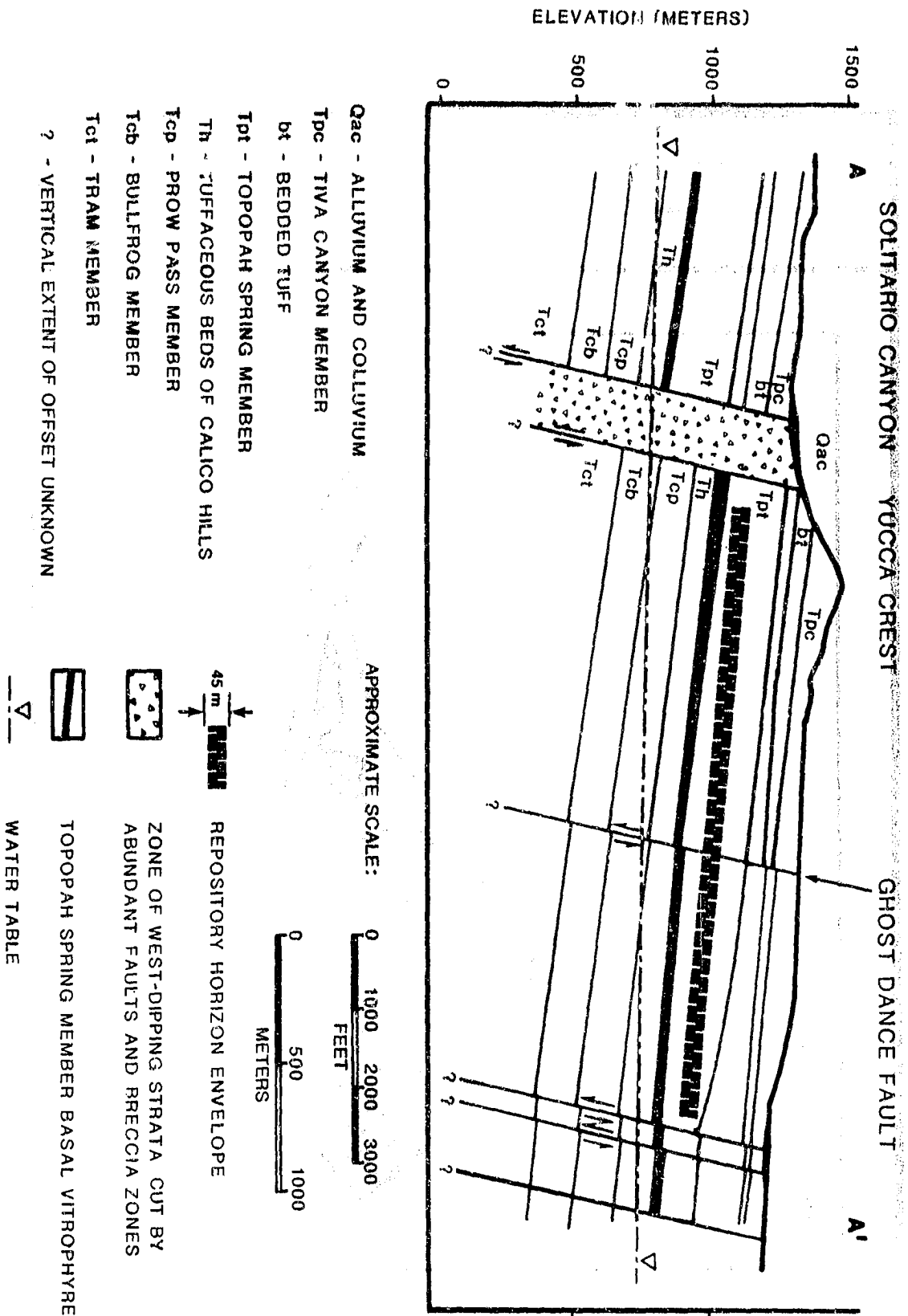
Figure 6-16. Approximately east-west cross section of primary repository area showing possible location of the underground repository envelope. For approximate location of cross section A-A', see map view in Figure 6-14. Modified from Mansure and Ortiz (1984).

Two points bear on the discussion of this condition for the Yucca Mountain site. First, the site is in the unsaturated zone. Favorable condition 5(iv) in Section 6.3.1.1 notes that for an unsaturated zone repository, freely draining strata are desirable, and Yucca Mountain meets this favorable condition. Second, the Topopah Spring Member is highly fractured. It is therefore expected that significant thermally induced expansion can occur without generating sufficient stresses to cause new fracturing.

The thermal conductivity and the coefficient of thermal expansion for a variety of rock types are shown in Table 6-29. The value for the coefficient of thermal expansion of all rock types shown in the table is low when compared with values for salt. The absolute values of the thermal conductivity and coefficient of thermal expansion can be meaningfully evaluated only when combined in an analysis that includes relevant physical properties, additional thermal and mechanical properties, details of repository design, canister loading, and gross thermal loading. Such analyses (Johnstone et al., 1984) have shown (1) that the effect of the repository on the surrounding rock is small because the rock can accommodate the expected mechanical and thermal stresses; and (2) that there is considerable flexibility in repository design, canister loading, and gross thermal loading to minimize the effect of any adverse rock response that may be identified in the future. The analyses indicate that the thermal conductivity and the thermal expansion coefficient of the densely welded Topopah Spring Member at Yucca Mountain will not adversely affect the containment and isolation capabilities of the repository.

Evaluation for ductility to seal fractures

The ability to seal fractures is not a favorable condition for a repository in the unsaturated zone. The sealing of fractures could lead to repository saturation because of the formation of a barrier to water flow and the development of a perched water zone that would not exist in a freely draining system.

The current data for the Topopah Spring matrix show essentially elastic behavior up to the onset of brittle failure. Typically, the axial strain to the point of failure in compressive tests does not exceed 1 percent. Studies of the effects of water and elevated temperatures on the mechanical behavior of tuff are under way, and results will be reported in the future. But according to present data, the Topopah Spring tuff does not have sufficient ductility to seal induced or preexisting fractures. As discussed under potentially adverse condition 3, it is unlikely that sealing will occur by other processes, such as mineral precipitation from solution.

Conclusion

The potential repository host rock at Yucca Mountain will accommodate the thermal and mechanical stresses developed during the period of peak temperatures with no adverse effect on waste containment and isolation. The coefficient of thermal expansion of tuff is low when compared to salt and the thermal conductivity is intermediate when compared to other common rock types.

Table 6-29.   Thermal rock properties for a variety of common rock types

Rock type	Temperature (°C)	Thermal conductivity (W/m-°C)	Thermal expansion (10^{-6}/°C)
Basalt[a]	20-200	1.5-1.6	6.0-6.5
Granite[b]	0-100	1.8	8.4
Salt[c]	50-250	2.6-3.4	36.5-46.5
Sandstone[d]	20-100	2.1	10 ± 2
Slate[b]	20-100	1.8	8.0 ± 1
Welded tuff[e]	Ambient to 200		
	Saturated	1.8 ± 0.4	10.7 ± 1.7
	Dry	1.6 ± 0.4	NA

[a] Data from DOE (1984a).
[b] Data from Tuma (1976).
[c] Data from DOE (1984b).
[d] Data from Clark (1966).
[e] Data from Tillerson and Nimick (1984).

The host rock is not sufficiently ductile to seal fractures; such sealing is, in fact, undesirable for a repository in the unsaturated zone. Therefore, the evidence indicates that this favorable condition is present at Yucca Mountain.

6.3.1.3.4   Potentially adverse conditions

(1)   Rock conditions that could require engineering measures beyond reasonably available technology for the construction, operation, and closure of the repository, if such measures are necessary to ensure waste containment or isolation.

Evaluation

The evaluation of the technology required to deal with rock conditions during the preclosure phase (Section 6.3.3.2) identified no situations that would require engineering measures beyond reasonably available technology. Rock conditions that could seriously threaten waste containment by the waste package, or waste isolation after the package is breached, are considered in

this section; they include the chemical environment, mechanical behavior (including the effects of heat), hydraulic conductivity, and shaft and borehole sealing. Most of the rock-property data collected to date are from surface mapping and measurements on core samples.

The chemical environment is benign with regard to the corrosion and leaching from the waste form (Section 6.3.1.2). Stress-induced corrosion could be of concern if the mechanical behavior of the rock subjects the waste disposal containers to severe stress. This problem is currently under investigation. The rock is expected to be strong, with little likelihood that blocks would fall on the waste containers and breach containment, although mining experience will be needed to confirm this expectation. Heat is expected to cause limited fracturing around the waste emplacement hole; limited testing in similar rock supports this expectation (Zimmerman, 1983). The rock fracturing is also expected to have minimal effect on containment and isolation. If the thermally induced rock fracturing around boreholes does become a problem, it appears to be solvable with reasonably available technology. Hole liners, emplaced to ensure retrievability, could both lessen and delay potential adverse effects but would not necessarily eliminate them. Work is continuing on the effects of heat and water on the mechanical behavior of the rock.

Hydrologically, the repository horizon is freely draining. At present, no difficulties have been identified regarding shaft and borehole sealing. Analyses indicate that no backfill is necessary in access or emplacement drifts. Shafts and ramps would be backfilled at the end of the retrieval period. A plug or seal would be used to support the surface barrier system in the shafts and separate it from the shaft interior, which would be filled with a coarse, unreactive material, such as crushed tuff. This material may be graded in size to minimize settlement, and additional plugs could be emplaced to provide support for fill immediately above each plug. The current plans are to use permeable plugs and backfill so that any water can drain to the bottom of the shaft. Removal of the concrete shaft liner from the junction of the shaft and access drifts to the bottom of the shaft would enhance drainage into fractures. Ramps would be sealed in a similar fashion except that dams could be installed at intervals to divert water flow. Exploratory boreholes extending below the repository level would be filled with grout, slurry, or a tamped substance containing sorptive materials. Plugs may be needed to support this material; below the plug, standard well-plugging procedures can be followed. Above the repository level or for shallow boreholes, a granular material or grout can be used (Fernandez and Freshley, 1984; Jackson, 1984). None of these sealing concepts are expected to require engineering measures beyond reasonably available technology.

Conclusion

No rock conditions have been identified at the Yucca Mountain site that would require extraordinary engineering measures to seal shafts and boreholes and to ensure waste containment and isolation. Existing technology is adequate for constructing, operating, and closing the repository in a manner consistent with the objectives of waste containment and isolation. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(2) Potential for such phenomena as thermally induced fractures, the hydration or dehydration of mineral components, brine migration, or other physical, chemical, or radiation-related phenomena that could be expected to affect waste containment or isolation.

Evaluation for thermally induced fractures

The potential host rock at Yucca Mountain is the Topopah Spring Member, which is a highly fractured (Spengler et al., 1979, 1981; Spengler and Chornack, 1984; Maldonado and Koether, 1983; Scott and Castellanos, 1984), unsaturated, densely welded tuff. In examining the thermomechanical response of the rock in the near and the far fields for short and long time periods, Johnstone et al. (1984) made calculations with state-of-the-art, finite-element, thermomechanical computer codes that accounted for fractures by a "ubiquitous joint model" and geologic layering (i.e., stratigraphy). These calculations are considered preliminary. Evaluations are under way to reduce the uncertainties in the model; however, confidence in the validity of the model is based upon mining experience and field tests in similar devitrified, densely welded tuff (G-Tunnel at Rainier Mesa). The physical, thermal, and mechanical properties were based on laboratory or field measurements for both average and limit values when available, or they were estimated by comparison with similar units if required data were not available. In particular, thermal-expansion coefficients that accurately describe the cristobalite phase transition in the Topopah Spring Member were available (see the evaluation of potentially adverse condition 4, Section 6.3.3.2). In situ stresses were estimated because no measurements had been made at the Yucca Mountain site when the evaluation began. Subsequent measurements were in reasonable agreement with the estimates (Johnstone et al., 1984; Healy et al., 1982). For a repository in the Topopah Spring Member with a gross thermal loading of 57 kilowatts per acre (approximately 3.0 kilowatts per container), calculations predicted no thermally induced fracturing of the matrix in either the near or the far field.

For a higher waste disposal container heat load of 3.3 kilowatts per container, thermomechanical calculations predict the potential for rock fracturing in the immediate vicinity (very near field) of the waste-emplacement hole, extending less than 10 centimeters (4 inches) into the rock. Such fracturing is not expected to affect waste containment or isolation. In spite of the possible decrease in thermal conductivity, such fracturing may be desirable because of the increased surface area available for radionuclide retardation. Hole-wall degradation has not been observed in small-diameter-heater tests in tuff at G-Tunnel (Zimmerman, 1983).

For the conditions used in the calculations by Johnstone et al. (1984), the results indicate that the potential for thermally induced fracturing is very low. More important, however, the repository thermal loading can be adjusted if it is discovered that thermal effects could become potentially adverse. With the expected low flux of less than 0.5 millimeter (0.02 inch) per year (see Section 6.3.1.1.5), no mechanisms have been recognized whereby thermally induced fractures could threaten containment of isolation performance at the Yucca Mountain site.

The mineral components that have the potential for hydration or dehydration are volcanic glass, smectites, and the zeolites clinoptilolite, mordenite, and analcime. The Topopah Spring Member contains little zeolite or volcanic glass in the horizon of interest. South of Drill Hole Wash, the member generally contains less than 3 percent smectite. More than 98 percent of the host rock within the primary repository area is composed of alkali feldspar, cristobalite, quartz, and tridymite; however, tridymite is generally not present in the potential repository horizon (Bish et al., 1984). Hydrous minerals are not present in the repository horizon in large enough quantities to cause significant dehydration effects. Rock units in Yucca Mountain at depths of 300 meters (984 feet) or more below the repository horizon contain an abundance of hydrous phases, including smectite, clinoptilolite, mordenite, and analcime (Bish et al., 1984). Cross sections of the zeolite intervals below the repository horizon are shown in figures 6-10 through 6-13 in Section 6.3.1.2. The extent to which dehydration and contraction will affect waste isolation, however, will depend on the distribution of hydrous minerals in the host rock, the temperature rise imposed on the minerals, and the water vapor pressure.

The maximum temperature experienced at 50 meters (160 feet) below the repository horizon is predicted to be well below 100°C (212°F) (Johnstone et al., 1984). Under these conditions, smectites, zeolites, and glass will dehydrate only if the water-vapor pressure is low (Bish, 1981; Bish et al., 1982). Assuming a gross thermal loading of 57 kilowatts per acre, maximum temperatures have been determined as a function of distance from a spent fuel repository (Morales, 1985). The center of the repository will reach a maximum temperature of 117°C (243°F) 60 years after emplacement, while the temperature would be 71°C (160°F) at the repository edge. Fifty meters (160 feet) beyond the repository edge, the temperature will peak at 49°C (120°F) at 111 years after emplacement. The calculations can be summarized by noting stand-off distances that are required to stay below a particular temperature. To ensure that temperatures never rise above 100°C (212 °F), you must be approximately 23 meters (75 feet) vertically above the center of the repository; the temperature at the edge of the repository will never reach 100°C (212°F). This indicates that dehydration of the minor amounts of zeolites or clays within the host rock (less than 2 percent) beyond a distance of about 23 meters (75 feet) is unlikely, and as indicated earlier, all major zeolitized rock units are at least 100 meters (328 feet) below the repository midplane (see Section 6.3.1.2).

Dehydration reactions involving smectites, clinoptilolite, and mordenite are reversible when heating is below 200°C (392°F) (Bish, 1981), and the presence of water vapor significantly increases the temperature of dehydration for smectites (Koster van Groos, 1981) and probably for zeolites. Therefore, such reactions, even if they occur in the far field, will probably be reversible and will not affect waste isolation.

One additional mineralogical factor that should be considered is the abundance of cristobalite in the very near field. The transition from alpha to beta cristobalite, occurring between 235 and 260°C (455 and 500°F) in confined tests (Lappin, 1980a), gives rise to a slightly increased thermal

expansion. Because of the high transformation temperature, the potential for this transformation to occur is limited to the very near field of the waste package and is unlikely to affect waste isolation because cristobalite is not important in retardation.

Evaluation for brine migration

Although brine is not found in the tuff at Yucca Mountain, several scenarios have been identified that could possibly concentrate halide ions in the ground water in the repository environment. These scenarios include (1) salt deposition on the waste container by evaporation of water dripping on the hot waste disposal container from a seeping fracture from a transient percolation event, followed by redissolution of these salts in the ground water, and (2) precipitation of halide salts contained in the ground water in the surrounding rock matrix as the rock dries out from the heat of the waste disposal container. Subsequent dissolution may occur when the rock is resaturated after the dry-out period.

A preliminary study was performed to determine if either of the above scenarios represent viable processes for concentrating halides in the ground water at Yucca Mountain (Morales, 1985). The first scenario is not relevant because the existence of a hot waste disposal container should prevent any slow seepages in its immediate vicinity from occurring. The second scenario could possibly increase salt concentrations in the rock surrounding the waste disposal container, but probably only by a factor of 10 and only for times immediately following the dry-out period. Furthermore, a mechanism for transporting the concentrated ground water across the borehole wall (and air gap) has not been identified. However, even if this groundwater could contact the waste container, performance (corrosion and waste-form dissolution) should not be adversely affected by such salt concentation increases. This topic will be addressed in more detail during site characterization.

Radiation-related phenomena

Investigations of the effects from gamma irradiation of different candidate stainless steels submerged in water from Well J-13 have begun. Preliminary results from these studies indicate that high-intensity gamma radiation increases the corrosion potentials of the stainless steels (DOE/NVO, 1985). The corrosion mechanism is thought to be the production of hydrogen peroxide, a strong oxidant, under gamma radiolysis of the water. This effect is expected to be insignificant under actual repository conditions, however, because heat from the waste disposal containers will probably dry out the immediate environment of the containers for 500 to 1,000 years after closure (Stein et al., 1984). Gamma radiation will have decreased to insignificant amounts before liquid phase radiolysis can occur. Thus, after the thermal period, the potential will no longer exist for increased oxidizing conditions due to radiolysis.

Conclusion

The potential host rock at Yucca Mountain is a physically and chemically stable, densely welded tuff that would be little affected by expected repository conditions. More than 98 percent of the rock is composed of alkali

feldspar, cristobalite, quartz, and tridymite, all nonhydrous minerals. The potential host rock is highly fractured, and any additional thermally induced fracturing would be minor and would not adversely affect waste containment or isolation. No other physical, chemical, or radiation-related phenomena have the potential for adversely affecting waste containment or isolation. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

(3) A combination of geologic structure, geochemical and thermal properties, and hydrologic conditions in the host roc and surrounding units such that the heat generated by the waste could significantly decrease the isolation provided by the host rock as compared with the pre-waste-emplacement conditions.

Evaluation

Three categories of heat-related effects have been identified as potentially applicable to this condition: (1) changes in the radionuclide retardation capability, (2) changes in host-rock permeability due to matrix dissolution, and (3) convective transport of radionuclide-contaminated ground water. The basis for evaluating each of these three concerns is discussed separately below.

Evaluation for thermal effects on radionuclide retardation

Heat-driven rock and ground-water interactions along with absolute temperature increases could affect radionuclide sorption and thus the retardation capability of the host rock. The rock and ground-water interactions could cause this by altering the mineral phases present and the ground-water solution chemistry. However, elevated-temperature experiments on the interaction of Topopah Spring tuff with water from Well J-13 indicate that an emplaced heat source should produce very little change in ground-water chemistry and primary mineralogy of the Topopah Spring Member (Oversby, 1983). This study also noted that the anionic composition (radionuclide-complexing agents) of the water remains relatively constant. Therefore, the effect of increased temperature on radionuclide solution chemistry should be minimal. The lack of significant thermally induced mineral alteration is also addressed in favorable condition 3 for geochemistry (Section 6.3.1.2).

The direct effect of higher water temperatures on the sorption process has been superficially investigated (Erdal et al., 1979; Johnstone and Wolfsberg, 1980; Daniels et al., 1982). These limited studies showed, that in general, temperature changes between 20 and 70°C (68 and 158°F) have only a minor effect on sorption. For most elements studied, sorption is slightly greater at the higher temperatures (sorption coefficients increased by up to a factor of 5). The exceptions include a few lanthanides and actinides, which showed very little or a slightly negative temperature response. As the temperature is increased, retardation because of diffusional processes will not be decreased.

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8 0 0 0 8   0 7 4 6

The heating and subsequent cooling of ground water as it flows through the host rock could induce mineral dissolution and precipitation processes, which, in turn, would change the permeability. Currently, the magnitude of the changes in permeability that would adversely affect isolation have not been identified. However, a study has been conducted that shows that, for the expected quantities of both porous and fracture flow, the potential porosity and permeability changes are not significant (Braithwaite and Nimick, 1984). In this analysis, it was assumed that the infiltrating ground water would maintain equilibrium saturation with respect to amorphous silica. This is a reasonable bounding assumption because of the following factors:

1. Dissolved-silica concentrations constitute a major control on silicate-phase dissolution (Wollast, 1967; White et al., 1980; McVay, 1982).

2. The predicted quantity of mass transfer is greater than that measured experimentally (Braithwaite and Nimick, 1984).

3. Rates of equilibration between ground-water and rock systems are very slow at the low temperatures predicted for waste isolation in the unsaturated zone (Oversby, 1983).

A predicted time-dependent temperature gradient was coupled with the assumptions about amorphous-silica compositional control to determine the net change in porosity as a function of time and position. The results for spent fuel loadings of both 57 and 90 kilowatts per acre indicated that the maximum cumulative increase in porosity would be a volume fraction of only 0.00005 and that a decrease in porosity would occur only near the repository horizon. The net precipitation is mainly due to water vaporization and would decrease the void fraction by approximately 0.00001. This latter result probably addresses the critical issue because precipitation during downstream cooling represents a potential for plugging pores or fractures. However, these small changes, even if restricted to existing fractures, are not sufficient to significantly affect permeability.

Laboratory experiments with tuff samples from the Topopah Spring Member (Moore et al., 1984) also support the idea that changes in host-rock permeability are likely to be very small. A core sample 7.6 centimeters (3 inches) in diameter with a hole in the center was subjected to a temperature gradient of 100°C (212°F) between the inner and the outer edge. Ground water from Well J-13 was passed through the sample under confining and pore pressures corresponding to a burial depth of 1.2 kilometers (0.75 mile). The permeability of the tuff at room temperature was 3 microdarcies. After heating to 150°C (302°F), the value increased to 6 microdarcies, slowly increased for 1 week to 10 microdarcies, and then remained stable for 2 weeks. These results provide laboratory support for the claims that permeability changes that could cause significant changes in transport are unlikely in the very near field. The pH of the fluids discharged from the low-temperature outer edge of the sample was very close to that of Well J-13 water, and the concentrations of ionized species remained low, near that of Well J-13 water.

Evaluation for the convective transport of radionuclide-contaminated ground water

Thermally induced convective transport could conceivably reduce the time of ground-water travel through the host rock. If this process occurred in ground water that had been in contact with the waste, a decrease in the isolation provided by the host rock could result. Convection can occur in both vapor and liquid phases.

Free convective liquid-water transport, which is caused by density differences or buoyancy effects, can occur in porous media saturated with water. A corresponding mechanism for the free convective transport of liquid water (and therefore radionuclides) in the unsaturated zone is difficult to formulate. Nevertheless, free convection in the saturated zone would place an upper bound on the possible effect in the unsaturated zone. A preliminary study of the effects of convection on energy transfer in a saturated tuff medium (Mondy et al., 1983), showed that even with a thermal driving force well over 100°C, the maximum effect of free convection (if it occurred) would be a very small temperature increase, 2 to 3°C (4 to 5°F), occurring for less than 60 years. The highest induced water velocity would be less than 1 millimeter (0.04 inch) per year. Overall flux through the host rock would remain limited to less than 0.5 millimeter (0.02 inch) per year, which is insufficient to cause radionuclide releases to the accessible environment that would exceed the U.S. Environmental Protection Agency limits (see Section 6.4.2). According to these results, the lower temperatures and the unsaturated conditions actually expected for Yucca Mountain should preclude a decrease in host-rock isolation due to the convective transport of radionuclide-bearing ground water.

Conclusion

No combinations of geologic structure, geochemical and thermal properties, and hydrologic conditions have been identified that would cause the host rock to respond to the waste-imposed heat load in such a way that waste isolation would be compromised. Neither thermally enhanced rock-water interactions nor thermal effects on sorption are expected to reduce the isolation potential of the host rock at Yucca Mountain. Permeability changes due to host-rock dissolution and precipitation processes should not be significant, and the convective transport of radionuclide-bearing ground water is not expected in the low-temperature, unsaturated conditions at Yucca Mountain. Therefore, the evidence indicates that this potentially adverse condition is not present at Yucca Mountain.

6.3.1.3.5 Evaluation and conclusion for the qualifying condition on the postclosure rock characteristics guideline

Evaluation

The evaluation of the site against the preclosure rock characteristics guideline (Section 6.3.3.2) discusses worker safety and the ease and cost of repository siting, construction, operation, and closure. The results of that

evaluation show that currently available technology will be sufficient for all engineering and safety requirements. In addition, no unusual or exotic materials will be required. The geohydrologic and geochemical conditions are described in sections 6.3.1.1 and 6.3.1.2, respectively. In both sections, Yucca Mountain is considered suitable for site characterization as a potential repository site.

The preliminary thermomechanical analyses in Johnstone et al. (1984) show that the repository host rock can accommodate expected mechanical and thermal stresses after closure. They also note that th. heat load can be adjusted to account for unforeseen problems. Mansure and Ortiz (1984) report that limited lateral flexibility in the placement of the repository in the primary area should be overcome by contiguous areas that are likely to be suitable for waste emplacement. The study of interactions among the waste, host rock, ground water, and engineered components is an ongoing task. To date, no difficulties have been identified. Because the repository would be in the unsaturated zone, ground-water interactions with the waste package could occur only at temperatures of less than 100°C (212°F). Above 100°C (212 °F) the water evaporates and moves to a cooler region. Such behavior tends to increase the effective thermal conductivity and to decrease the temperature in the rock mass near the heat source. As noted in potentially adverse condition 2, this steam condenses a short distance from the waste disposal containers. The effects of heat and water on the mechanical response of the Topopah Spring Member are under study. The opening, closing, or creation of fractures around the repository is not expected to affect steady-state percolation rates, because very little fracture flow is expected in the repository host rock at the upper bound on flux of 0.5 millimeter (0.02 inch) per year (Wilson, 1985).

Conclusion

A preliminary analysis of the Yucca Mountain site indicates that the present and expected characteristics of the host rock and the surrounding units will permit compliance with the requirements specified in 10 CFR 960.4-1 (1984) and 10 CFR 60.113 (1983). Furthermore, as reviewed in Section 6.4.2, the results of a preliminary performance analysis, using available rock-characteristics data and an upper bound on flux of 0.5 millimeter (0.02 inch) per year lend considerable confidence to the expectation that detailed site characterization will support preliminary results. Evidence to date indicates that the engineered barrier system will limit radionuclide releases to less than 1 part in 100,000 of the 1,000-year inventory. No potential interactions among the waste, host rock, ground water, and engineered components that could compromise waste isolation have been identified. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition for postclosure rock characteristics (level 3).

6.3.1.3.6 Plans for site characterization

A number of tests are planned to supplement the existing rock characteristics data base. Overcore tests to determine in situ stresses in Yucca

Mountain will be performed at three levels during construction of the exploratory shaft. An enhanced heated block experiment is planned for exploratory-shaft in situ testing to determine the rock response to induced stress and thermal changes. Permeability changes in selected fractures under various stress and thermal loads will also be measured. A large-scale-heater experiment will be conducted to evaluate the near field rock response to waste-imposed thermal loads. Thermal, thermomechanical, and hydrothermal measurements will be made and used to establish the behavior of the host rock to be expected after repository closure, particularly with regard to any possible thermal effects on retardation.

6.3.1.4 Climatic changes (10 CFR 960.4-2-4)

6.3.1.4.1 Introduction

The qualifying condition for this guideline is as follows:

The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.

Climatic changes could, over time, alter the geohydrologic system at a site. This postclosure guideline on climatic changes is concerned with changes that may favorably or unfavorably affect the ability of a repository to isolate waste after closure.

The guideline consists of two favorable conditions, two potentially adverse conditions, and one qualifying condition. The evaluations presented below are summarized in Table 6-30.

6.3.1.4.2 Data relevant to the evaluation

The climates of the Nevada Test Site and its vicinity during the last 45,000 years have been reconstructed (Spaulding, 1983; Spaulding et al., 1984) largely on the evidence of plant macrofossils found in the middens of pack rats (genus Neotoma). These authors also review the literature on global and regional climatic changes and predict future climatic variations. Thompson and Mead (1982) also examined pack-rat middens and found the presence of subalpine and boreal mammals at relatively low elevations during the late Wisconsin.

Uplift of the Sierra Nevada and Transverse ranges may have long-term effects on the climate of Nevada. During the Quaternary, increasing aridity in Nevada has been attributed to this uplift (Winograd et al., 1985). Estimates of the uplift of the Sierra Nevada are discussed in Huber (1981) and Hay (1976).

Table 6-30. Summary of analyses for Section 6.3.1.4; climatic changes (10 CFR 960.4-2-4)

Condition	Department of Energy (DOE) finding
FAVORABLE CONDITIONS	
(1) A surface-water system such that expected climatic cycles over the next 100,000 years would not adversely affect waste isolation.	The evidence indicates that this favorable condition is present at Yucca Mountain: regional and site surface-water systems probably have been the same for several-hundred thousand years; expected climatic changes will not significantly change surface water systems.
(2) A geologic setting in which climatic changes have had little effect on the hydrologic system throughout the Quaternary Period.	The evidence indicates that this favorable condition is not present at Yucca Mountain: Quaternary climates were probably not substantially different from modern climates; however, increased flux and higher water tables probably occurred within the geologic setting during the Quaternary Period.
POTENTIALLY ADVERSE CONDITIONS	
(1) Evidence that the water table could rise sufficiently over the next 10,000 years to saturate the underground facility in a previously unsaturated host rock.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: there is no evidence that the water table was ever as high as the proposed repository level; climatic changes are not expected to cause sufficient water-table rise to flood the repository.
(2) Evidence that climatic changes over the next 10,000 years could cause perturbations in the hydraulic gradient, the hydraulic conductivity, the effective porosity, or the ground-water flux through the host rock and surrounding geohydrologic units, sufficient to significantly increase the transport of radionuclides to the accessible environment.	The evidence indicates that this potentially adverse condition is not present at Yucca Mountain: increased precipitation could increase unsaturated zone flux, but major changes in hydraulic conditions are not expected over the next 10,000 years. If flux in the host rock was much higher than present, the site would still be expected to meet EPA limits at the accessible environment in 10,000 years.

Table 6-30. Summary of analyses for Section 6.3.1.4; climatic changes (10 CFR 960.4-2-4) (continued)

Condition	Department of Energy (DOE) finding

QUALIFYING CONDITION

The site shall be located where future climatic conditions will not be likely to lead to radionu- clide releases greater than those allowable under the requirements specified in Section 960.4-1.

Existing information does not support the finding that the site is not likely to meet the qualifying condition (level 3): expected climatic changes will not cause significant changes in surface drainage; unsaturated-zone flux may increase, and the water- table altitude may rise, but radionuclide releases are not likely to exceed the release limits.

Regional hydrology was described by Winograd and Thordarson (1975). Ground-water flow systems in the vicinity of Yucca Mountain were investigated by Czarnecki and Waddell (1984). Site-specific hydrologic data are presented by Thordarson (1983) and Robison (1984). Current precipitation data for nearby areas are presented in Quiring (1983).

There are also some data and interpretations about Pleistocene water-table levels, ground-water recharge, and pluvial lake formation in areas adjacent to Yucca Mountain. Winograd et al. (1983) described the late-Pleistocene hydrologic conditions of the Ash Meadows ground-water basin; their interpretation is based on the distribution of calcite veins in alluvium and lake beds, as well as fossil spring deposits of tufa. The mineralogy of the fine portion of the matrix samples of alluvium, taken from boreholes north of Frenchman Flat, suggests long-term stability of water-table levels during the Quaternary Period (Jones, 1982).

Climatic changes resulting in pluvial conditions would have affected the hydrologic system during the Quaternary. Effects of increased recharge on the water-table altitude were modeled by Czarnecki (1985) using a two-dimensional, finite-element ground-water flow model. Work done by Travis et al. (1984) indicates that pluvial conditions are likely to increase ground-water travel times.

Another result of a rise in the ground-water table could be the alteration of the vitric pumice (Hoover, 1968). Mineralogy and petrology of Yucca Mountain tuffs are discussed by Bish et al. (1984).

The mechanisms of recharge in the west central Amargosa Desert between 17,000 and 9,000 years ago have been inferred by Claassen (1983) from carbon, hydrogen, and oxygen isotope data. Evidence for pluvial lakes in Nevada during the last glacial episode has been interpreted by Mifflin and Wheat (1979). Lacustrine deposits in the Amargosa Valley and Crater Flat areas are considered to be Quaternary-Tertiary in age by Hoover et al. (1981) and Swadley (1983).

Assumptions and data uncertainties

The evidence that would allow reliable reconstructions of early to middle Pleistocene climates at Yucca Mountain is limited because of the absence of glacial deposits in the area and the incompleteness of the pedologic and geologic records. Consequently, it is assumed that the climatic extremes inferred from evidence of late Wisconsin age (Spaulding, 1983; Spaulding et al., 1984) would be typical of all Quaternary time. Predictions of the nature of future climatic changes were also made for some of the analyses in this section. The uncertainties implicit in these predictions are not quantifiable but are probably large, and the predictions are useful only for establishing reasonable bounds on estimates of climatic parameters.

The late-Pleistocene reconstruction of the Ash Meadows ground-water basin by Winograd and Doty (1980) does not specifically apply to Yucca Mountain because the latter is in the Alkali Flat-Furnace Creek Ranch ground-water basin (Waddell, 1982). However, the reconstructions developed for the

Ash Meadows basin should be generally applicable to ground-water basins in the Death Valley ground-water system. No definitive evidence of Quaternary water levels has been found during preliminary investigation of tuff minerals from Yucca Mountain (see geochemistry favorable condition 1, Section 6.3.1.2). The effects of pluvial conditions on flow paths and water levels beneath Yucca Mountain are being studied with mathematical models of the regional and local hydraulic systems.

Current understanding of the relation between precipitation and recharge to the water table beneath Yucca Mountain is discussed in Section 6.3.1.1.5, where a value of 0.5 millimeter (0.02 inch) per year is justified as an upper bound on local recharge to the water table beneath Yucca Mountain. Conceptual models of flow in the unsaturated zone are not yet sufficiently developed to permit quantitative testing of the relations among precipitation, net infiltration, percolation, and recharge. Analyses of the effects on waste isolation of climatic changes made to date are largely qualitative. When quantitative analyses are made, they will rely heavily on preliminary performance analyses and on preliminary analyses of system-parameter sensitivities. Preliminary performance analyses and parameter studies will be updated as data on the site are acquired. The first available versions are summarized in Section 6.4.2 and in Sinnock et al. (1984).

6.3.1.4.3 Favorable conditions

(1) A surface-water system such that expected climatic cycles over the next 100,000 years would not adversely affect waste isolation.

Evaluation

Because past geohydrologic events and processes are probably the best indicators of future conditions, a discussion of the regional climate during the Quaternary is included in the evaluation of this favorable condition. Pluvial climates probably had little effect on the principal surface-water features of the region. By early Quaternary time, lakes of Tertiary age that had existed in the Amargosa Valley and Crater Flat areas had disappeared, although the range of ages of the associated lacustrine deposits is not well known. These deposits are considered to be Quaternary-Tertiary in age by Hoover et al. (1981) and Swadley (1983). According to the reconnaissance studies of Mifflin and Wheat (1979), the pluvial climates that periodically occurred during the remainder of the Quaternary did not cause perennial lakes to form in southern Nevada, like those that existed in central and northern Nevada.

Surface-water drainage basins in the Yucca Mountain region were probably well established by early Quaternary time, and the closed surface-water and ground-water basins that exist today existed throughout the Quaternary. Although Lake Amargosa may have continued into early Quaternary, throughout most of this period the Amargosa River drainage system was integrated with Death Valley. The tributary Fortymile Wash drainage system and the bedrock washes dissecting Yucca Mountain and other ranges were also established by